National Park Service
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Natural Resource Stewardship and Science

Freshwater Quality Monitoring in the San Francisco Bay Area Network

2011-2012 Biennial Report

Natural Resource Technical Report NPS/SFAN/NRTR—2013/801

ON THE COVER (clockwise, from upper left.) Photographs by Angela Pincetich & Katie Wallitner
Bear Gulch (site BG2), Pinnacles National Park.
Tennessee Valley Creek (site TV3), Golden Gate National Recreation Area.
John West Fork (site OLM1), Point Reyes National Seashore.
Franklin Creek (site FRA1), John Muir National Historic Site.

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Executive Summary

The National Park Service (NPS) San Francisco Bay Area Network (SFAN) Inventory and Monitoring Program monitors freshwater streams in John Muir National Historic Site (JOMU), the Presidio of San Francisco (PRSF), Muir Woods National Monument (MUWO), Pinnacles National Park (PINN), Point Reyes National Seashore (PORE), and Golden Gate National Recreation Area (GOGA). SFAN vital signs, or indicators of ecosystem health, represent a suite of ecological phenomena operating at a range of temporal and spatial scales; SFAN managers and specialists ranked freshwater quality as one of the most important vital signs (Adams et al. 2006). SFAN units support highly-valued aquatic resources that are significant in an ecological and economic context, including many federally protected species.

Water years (WYs) run from October 1st to September 30th of each year. This report summarizes water quality data from 30 SFAN sites monitored during WYs 2011 and 2012 (10/1/2010 – 9/30/2012), including nine sites in PORE, eight in PINN, seven in GOGA, and six in JOMU. During WYs 2011-2012, NPS staff made a total of 664 visits to these sites; visits occurred monthly and additionally during storm events. During these visits staff collected data regarding selected water quality parameters employing the methods set forth in the peer-reviewed SFAN Freshwater Quality Monitoring Protocol (Cooprider and Carson 2006). Core parameters measured in the field included temperature (air and water), dissolved oxygen, pH, specific conductance, and turbidity; samples collected in the field were tested for pathogenic indicator bacteria (*Escherichia coli [E. coli]* and total coliform) and nutrient parameters (nitrate as nitrogen and total Kjeldahl nitrogen [TKN]). Staff conducted fecal coliform sampling monthly at the Olema Creek watershed sites, as well as weekly sampling during five-week regimens (once each winter and summer) in collaboration with the San Francisco Bay Regional Water Quality Control Board's (RWQCB) Tomales Bay Pathogen Total Maximum Daily Load (TMDL) program.

Only half of the SFAN freshwater quality parameters have established objectives[1] put in place by the RWQCBs or the United States Environmental Protection Agency (EPA); other parameters (temperature, specific conductance, turbidity, and nitrate) do not have established water quality objectives, and are compared to ecological objectives drawn from scientific literature. In this report, the percentage of results that fail to meet any type of objective will be referred to as the "failure rate". In WYs 2011-2012 SFAN waters commonly met the water quality objectives. When grouping SFAN water quality results from all site visits in WYs 2011-2012, pH, nitrate (as nitrogen), and fecal coliform results most frequently met the objectives: only two percent of pH results failed to fall within their objective ranges; less than three percent of nutrient samples exceeded the ecological objective maximum of 1.1 mg/L nitrate (as nitrogen); and six percent of fecal coliform results exceeded the contact recreation objective maximum of 400 MPN/100mL. Overall, the nitrate (as nitrogen) dataset had a low exceedance rate; however, nearly all of these exceedances (12 of 13) were from Franklin Creek in JOMU.

[1] Numerical water quality objectives referred to throughout this report do not overlap in meaning with the monitoring program's operational or methodological objectives.

For all sites, the failure rates of other parameters (dissolved oxygen, total coliform, and *E. coli*) ranged from 12 to 18%. However, due to the variability between watersheds, much higher failure rates were revealed when grouping results by NPS unit. Overall, the PORE results commonly met their respective objectives, while the JOMU results rarely met the water quality objectives for most monitored parameters; the PINN and GOGA results exhibited highly varied exceedance rates. The JOMU dataset exhibited the highest failure rates for total coliform and *E. coli* when compared to the three other NPS units. Conversely, the PINN and GOGA datasets produced the highest dissolved oxygen failure rates (24% and 18%, respectively), while the PORE and JOMU datasets commonly met the dissolved oxygen objective (7% and 4% failure rates).

During WYs 2011-2012, the parameter with the highest failure rate was *E. coli*; 18% of all SFAN *E. coli* results exceeded the contact recreation objective maximum of 235 MPN/100mL. The JOMU dataset failed to meet the *E. coli* objective at a rate of 76%, while the PINN, PORE, and GOGA datasets exhibited lower failure rates (20%, 15%, and 13%, respectively). The majority of the PORE *E. coli* exceedances (89%) were from the Olema Creek sites, while very few exceedances were recorded at the Pine Gulch sites. High levels of pathogenic indicator bacteria in the Olema Creek watershed have been documented for many years, which is why the state-mandated TMDL program requires additional sampling of the six Olema Creek watershed sites; the fecal coliform results from these sites failed to meet the recreational objective (400 MPN/100mL) at a rate of six percent.

Two additional parameters – turbidity and specific conductance – do not have established water quality objectives, but they produced a significant number of failures when compared to ecological objectives. Fourteen percent of all SFAN turbidity samples were above the ecological objective maximum of 25 NTU, a level that has been shown to cause reductions in salmonid growth (Sigler et al. 1984); failures were found in each park unit. The ecological objective maximum for specific conductance is 500 µS/cm, in order to support diverse aquatic life (Behar 1997). Fifteen percent of all SFAN specific conductance results exceeded this objective; however, these results varied greatly by park. The PORE sites didn’t produce any exceedances, while the PINN and JOMU datasets failed to meet the objective at rates of 40% and 92%, respectively.

Monitoring efforts during WYs 2011 and 2012 produced a clear depiction of water quality in eight watersheds (within four NPS units). Due to the two-year rotating basin design of the SFAN Freshwater Quality Monitoring Protocol, this specific set of 30 sites will not be monitored again until WYs 2015-2016 (Cooprider and Carson 2006). The only exception to the rotating basin design is the set of six Olema Creek watershed sites, which require year-round monitoring under the Tomales Bay Pathogen TMDL Program. During WYs 2013-2014, this freshwater quality monitoring program will continue at 25 sites within PORE, MUWO, and GOGA.

Acknowledgments

This monitoring would not be possible without assistance from the Water Resources Division of the National Park Service, and support from individual SFAN parks and network staff. Thank you to Dean Tucker and Dale Roberts who provided assistance with database management, software updates, and data storage and handling, and thank you to Angela Pincetich who conducted a tremendous amount of field work and data management.

List of Terms

CFS	Cubic Feet per Second
EPA	(United States) Environmental Protection Agency
GOGA	Golden Gate National Recreation Area
JOMU	John Muir National Historic Site
MPN	Most Probable Number (of colony-forming units per 100 mL)
MUWO	Muir Woods National Monument
MQO	Measurement Quality Objectives
NPS	National Park Service
NPSTORET	National Park Service's version of the EPA STORET database
PINN	Pinnacles National Park
PORE	Point Reyes National Seashore
PRSF	The Presidio of San Francisco
QC	Quality Control
RDL	Reporting Detection Limit
RPD	Relative Percent Difference
RWQCB	Regional Water Quality Control Board
SFAN	San Francisco Bay Area Network (of the National Park Service)
STORET	Storage and Retrieval (EPA's water quality database)
TC/EC	Total coliform and *E. coli*
TKN	Total Kjeldahl Nitrogen
TMDL	Total Maximum Daily Load
USGS	United States Geological Survey
WY	Water Year

Introduction

Background

The National Park Service (NPS) *Management Policies* (NPS 2006) state that NPS managers will "use qualitative and quantitative techniques to monitor key aspects of resources and processes at regular intervals." The Inventory and Monitoring (I&M) program was established to help accomplish that mandate. Under the I&M program, San Francisco Bay Area Network (SFAN) staff monitor freshwater quality in six NPS units: John Muir National Historic Site (JOMU), the Presidio of San Francisco (PRSF), Muir Woods National Monument (MUWO), Point Reyes National Seashore (PORE), Golden Gate National Recreation Area (GOGA), and Pinnacles National Park (PINN) (Figure 1). The California Environmental Protection Agency regulates water quality through the State Water Resources Control Board which is divided into nine Regional Water Quality Control Boards (RWQCBs). All SFAN park units, with the exception of PINN, fall under the regulation of the San Francisco Bay RWQCB; PINN is within the Central Coast RWQCB area. Through Basin Plans, the RWQCBs have identified "beneficial uses" for water bodies, and numerical and narrative water quality objectives (also referred to as standards) to meet the uses. In each Basin Plan there are specific numerical objectives for pH, dissolved oxygen, and pathogenic indicator bacteria; there are no established objectives for nitrates, temperature, specific conductance, or turbidity. In the SFAN, freshwater quality monitoring is conducted under the SFAN Freshwater Quality Monitoring Protocol, which contains a thorough narrative and twelve standard operating procedures (SOPs) describing sampling locations, quality assurance procedures, field and laboratory methods, and data management procedures (Cooprider and Carson 2006). The PRSF sites are monitored through an agreement with the Presidio Trust; this program follows the SOPs of the SFAN Protocol, but is managed and reported on independently.

Freshwater streams within the SFAN support a range of federally protected and culturally important species including the California freshwater shrimp (*Syncaris pacifica*) [FE[1]], coho salmon (*Oncorhynchus kisutch*) [FE[1]/SE[2]], steelhead trout (*Oncorhynchus mykiss*) [FT[3]], and California red-legged frog (*Rana draytonii*) [FT[3]]. Also, streams in the network are valued for beneficial uses including contact and non-contact recreation, fish spawning and migration, cold freshwater habitat, and terrestrial wildlife habitat. Water quality in these streams has a direct impact on associated resources including marine waters, riparian habitat, wetlands, and the aquatic and terrestrial species dependent on these habitats.

[1] FE – federally endangered
[2] SE – state endangered
[3] FT – federally threatened

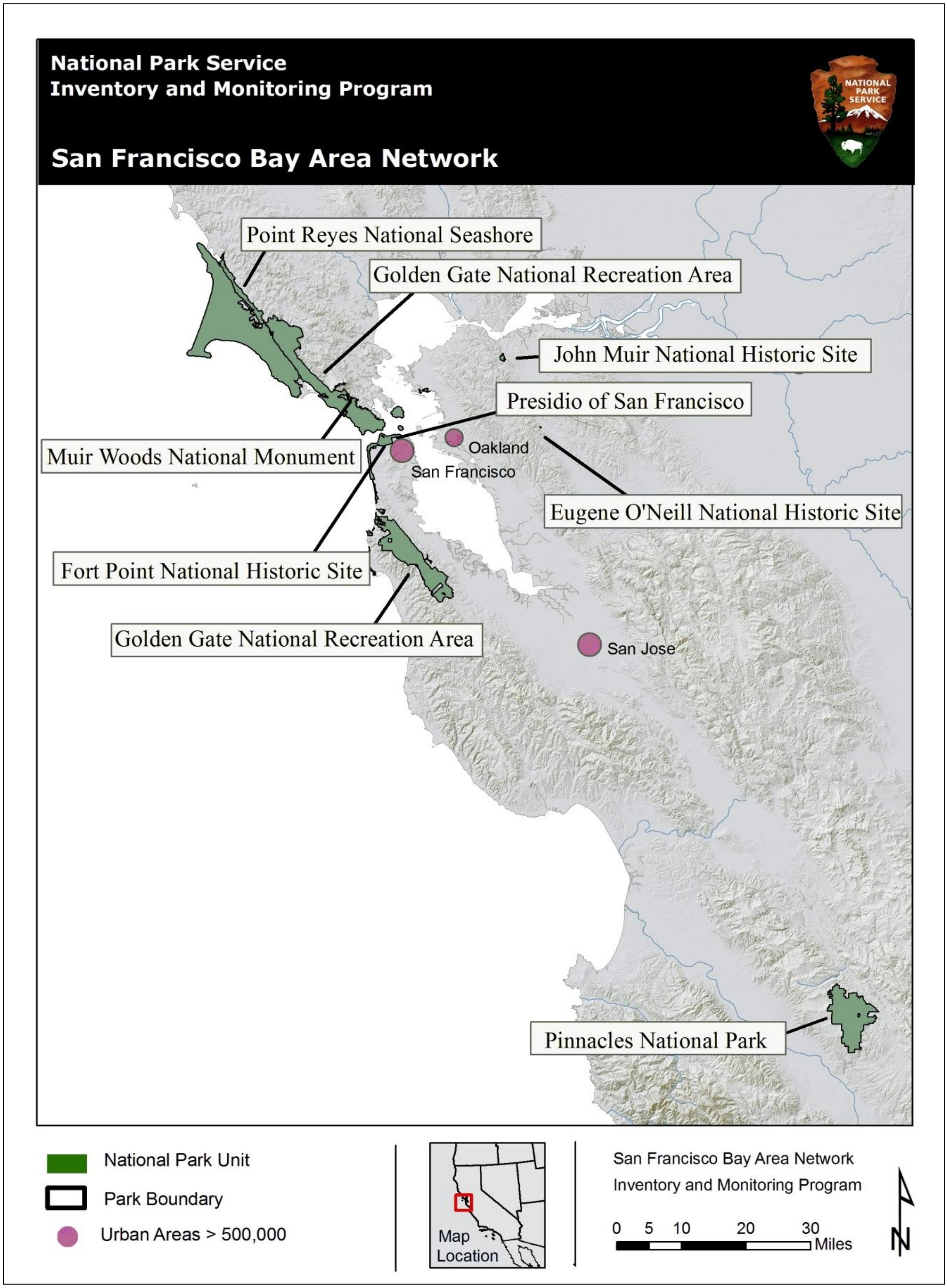

Figure 1. Map of the San Francisco Bay Area Inventory and Monitoring Network.

Objectives
Monitoring objectives as stated in the SFAN Freshwater Quality Monitoring Protocol are:

- Determine variability and long-term trends in water quality through monthly summaries of select parameters (water temperature, pH, conductivity, dissolved oxygen, total nitrogen, nitrate, ammonia, discharge, fecal and total coliform) at selected sites in priority freshwater streams within SFAN.
- Determine the existing ranges and diurnal variability of water temperature, pH, conductivity, and dissolved oxygen at selected sites in priority streams within SFAN.
- Determine the extent that selected sites in priority streams within SFAN meet federal and state water quality standards for fecal indicator bacteria, un-ionized ammonia, dissolved oxygen, and pH through monthly sampling.
- Determine the annual, seasonal, and 30-day mean fecal coliform load to Tomales Bay (an impaired water body) from Olema Creek as required by the San Francisco Bay RWQCB's Tomales Bay Pathogen Total Maximum Daily Load (TMDL) Program.

The goal of this report is to present data collected from the SFAN water quality sites during two consecutive water years (WYs) of monitoring. This report presents ranges and summary statistics of physical, chemical, and biological parameters measured at the SFAN water quality sites during WYs 2011-2012 (October 1, 2010 – September 30, 2012). Some of the monitoring questions and program objectives set forth in the protocol are not addressed in this report. Diurnal variability has not been measured because of significant needs for additional funding, staff time, and continuous monitoring equipment. Additionally, loading is not calculated as part of the RWQCB's TMDL program, and long-term trends can not be studied until there is a larger dataset; this will be evaluated by a statistician after 2014 (when there will be four years of data for every site) to determine the feasibility of trends analysis.

Overview of Aquatic Resources
Watershed lands within and around SFAN park units represent a range of land uses and various levels of anthropogenic modification. These lands include both coastal wilderness and watersheds surrounded by urban development. Land uses within the rural watersheds include agriculture, ranching, and commercial recreation operations (e.g., equestrian operations) as well as protected wilderness areas.

The Mediterranean climate of the San Francisco Bay Region is characterized by wet winters and dry summer months. Local streams are flashy, with high runoff in the winter and very low to intermittent flow during summer and early fall. In response to flashy hydrologic conditions and the highly active geologic processes associated with the San Andreas Fault, stream channel morphology is highly dynamic. Chalone Creek in PINN includes a highly mobile sand bed that is typically dry in the summer months. Watersheds in JOMU and portions of GOGA are greatly altered by development and urbanization, with some natural processes engineered out of the stream system. Watersheds within PORE, and the Marin and San Mateo County portions of GOGA, are less altered, and most of the smaller watersheds support anadromous steelhead trout. The larger PORE and northern GOGA watersheds, including Lagunitas, Olema, Redwood, and Pine Gulch, are documented to support both coho salmon and steelhead. Stream systems in these areas have been degraded by historic and current agricultural activities, and low-intensity residential development.

Several NPS efforts to improve ecological function of aquatic habitat within SFAN watersheds are underway. The Redwood Creek watershed (MUWO/GOGA) is currently the focus of a variety of projects including watershed planning, transportation planning, water quality investigations, sensitive species monitoring, riparian restoration projects, invasive/non-native plant removal, and habitat restoration. Several stream restoration projects are on-going at PORE including implementation of rangeland water quality best management practices, as well as habitat restoration projects. Restoration efforts in PINN are also on-going; recent projects include yellow star thistle removal, pig exclusion, and the relocation of various structures to enhance stream function.

Study Areas

Due to the rotating basin design of the SFAN Freshwater Quality Monitoring Protocol, the type of sites and number of watersheds monitored, alternate during each two-year rotation. During WYs 2007-2008, there were 30 monitoring sites in eight different watersheds, within four SFAN parks (PORE, PINN, GOGA, and JOMU). Larger watersheds were selected for the alternate rotation (during WYs 2009-2010), encompassing 25 monitoring sites in three different watersheds (within GOGA, MUWO, and PORE). Monitoring of the previous 30 sites resumed during WYs 2011-2012, and this alternating sampling routine will most likely continue throughout the life of this long-term monitoring program. The watersheds monitored during WYs 2011-2012 are introduced briefly below; more background information on site selection criteria, rationale, and sampling design can be found in the SFAN Freshwater Quality Monitoring Protocol (Cooprider and Carson 2006). The 2006 protocol identifies sites as *proposed* or *alternate*, but in this report they will be referred to as *primary* and *secondary* sites, respectively. Primary and secondary sites are monitored at the same frequency, but involve slightly different parameters (see Methods section for more information).

Point Reyes National Seashore (PORE)

The 88 square-mile Lagunitas Creek watershed is the largest within the SFAN. The mainstem flows north from Mount Tamalpais through a series of lakes and dams, eventually flowing through NPS lands (PORE/GOGA) before reaching the head of Tomales Bay near the town of Point Reyes Station. Stream discharge records range from 22,100 cubic feet per second (cfs) in the floods of January 1982, to 0.01 cfs during the drought of 1977 (Freeman et al. 2003). Within NPS lands there are several tributaries of Lagunitas Creek, including Olema Creek, Bear Valley Creek, Haggerty Gulch, and Tomasini Creek. The San Francisco Bay RWQCB has identified Lagunitas and Olema Creek as impaired by pathogens, sediment, and nutrients.

Olema Creek is the largest tributary of Lagunitas Creek, with stream discharge records up to approximately 3,000 cfs (Cooprider 2004). This 14.5 square-mile watershed flows north through the Olema Valley (the landward expression of the San Andreas Fault Zone). Its confluence with Lagunitas Creek lies at the head of Tomales Bay. Approximately 35-40% of the Olema Creek watershed is managed for cattle grazing. Two horse concession operations, Stewart Horse Camp and Five Brooks Stable, are located in the central portion of the watershed. Lagunitas Creek and Olema Creek support viable populations of coho, steelhead, and California red-legged frogs. Because these two creeks provide significant habitat for threatened and endangered species, and also because they are sources of pollutant loading to Tomales Bay, they are the subject of extensive monitoring through this water quality program as well as through the SFAN Coho and Steelhead Monitoring Program, the Salmon Protection and Watershed Network, and Marin Municipal Water District’s Lagunitas Creek Fisheries Program. NPS staff began hydrologic monitoring of Olema Creek in 1997 with the installation of a stream gaging station at the Bear Valley Road Bridge. Water quality monitoring within the Olema Creek watershed has been conducted since 1999, and fisheries monitoring (focused on coho and steelhead) has been conducted in the Olema Creek watershed since 1994. Water quality monitoring under the SFAN Freshwater Quality Monitoring Protocol began in the fall of 2006.

The Pine Gulch watershed extends over approximately 7.5 square miles, situated at the southern end of the Olema Valley. Pine Gulch flows parallel to Olema Creek, although in the opposite direction (south toward Bolinas Lagoon) because they are separated by the San Andreas Fault. Much of the downstream portion of the watershed is situated on private lands. Pine Gulch supports a viable population of steelhead and an intermittent population of coho, both monitored by the SFAN Coho and Steelhead Monitoring Program.

Three Pine Gulch sites and six Olema Creek watershed sites were included in the SFAN Freshwater Quality Monitoring sampling regime during WYs 2011-2012 (Table 1 and Figure 2).

Table 1. Freshwater quality monitoring sites within Point Reyes National Seashore.

Site	Site Type	Flow Regime	Site Description
OLM18	Primary	Intermittent	Olema Creek: upstream of Randall Gulch (near Hwy 1 milepost 21.06)
OLM1	Primary	Intermittent	John West Fork: upstream of Highway 1 culvert (near milepost 22.67)
OLM14	Primary	Perennial	Olema Creek: just downstream of the northernmost Five Brooks bridge
OLM6A	Primary	Perennial	Davis Boucher Creek: approximately 50 m upstream of footbridge, above confluence with Olema Creek
OLM11	Primary	Perennial	Olema Creek: at Bear Valley Road bridge
OLM10B	Primary	Perennial	Olema Creek: adjacent to Olema Marsh, below residence #530
PNG3	Primary	Perennial	Pine Gulch Creek: near Teixeira Ranch, just upstream of the Olema Valley Trail creek crossing
PNG2	Primary	Perennial	Pine Gulch Creek: west of Hwy 1, just north of Dogtown
PNG1	Primary	Perennial	Pine Gulch Creek: downstream of Olema-Bolinas Road bridge, at Gospel Flats Farm footbridge

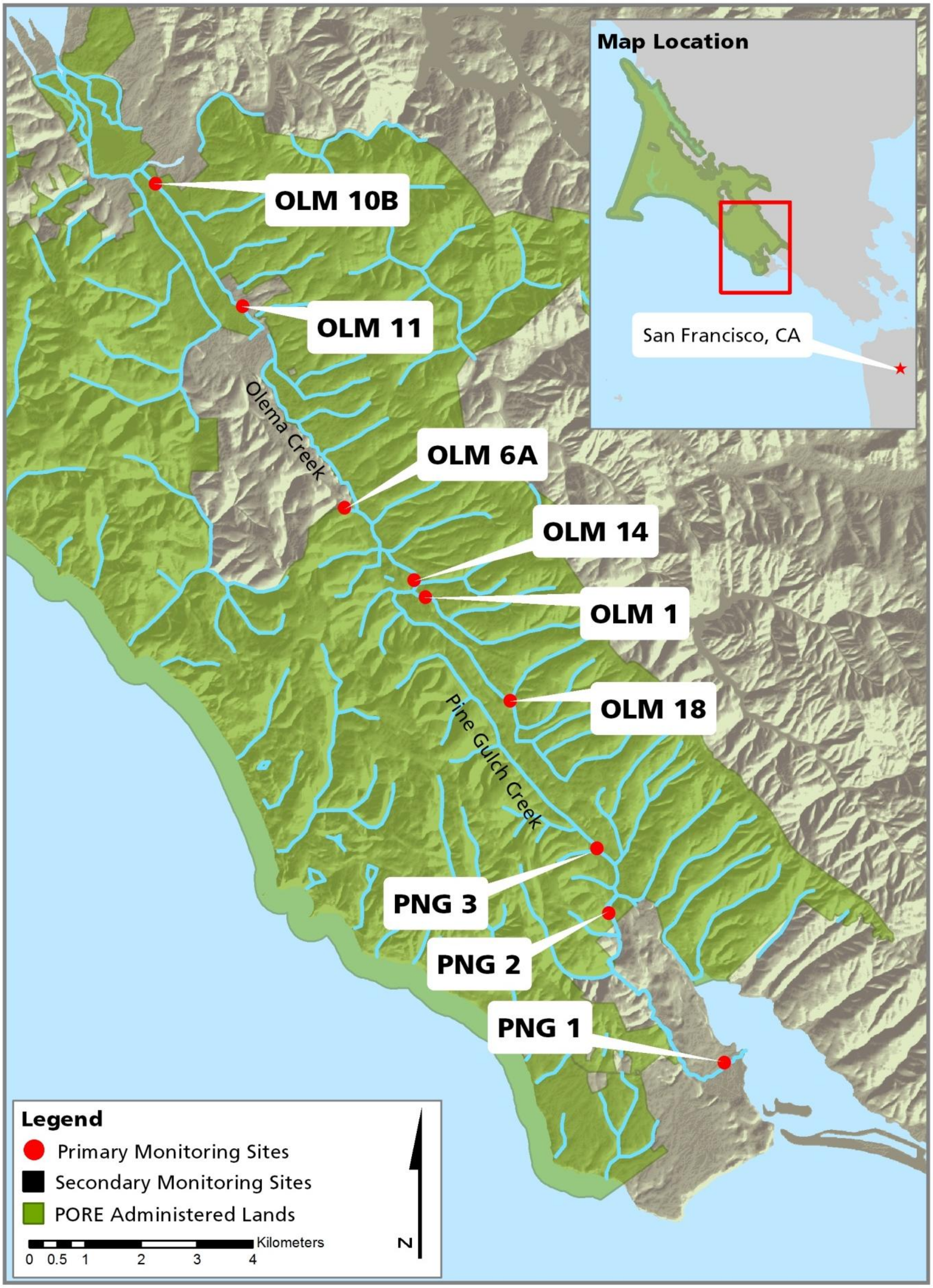

Figure 2. Freshwater quality monitoring sites within Point Reyes National Seashore.

Pinnacles National Park (PINN)

Ninety-five percent of PINN is located within the Chalone Creek watershed, which eventually drains into the Salinas River, southwest of the park. The Chalone Creek watershed drainage area is approximately 70 square miles; most of the Creek's headwaters are located outside the park boundary. The majority of Chalone Creek (within the park) is intermittent, commonly exhibiting dry conditions for five to six months per year, although some short reaches have water present year-round.

During WY2011, new pig exclusion fencing was completed with the addition of a nine-mile section in the northeastern portion of the park. The eradication of pigs from within the exclosure expansion is expected to provide substantial benefits to the ecological function of the Chalone Creek watershed, due to the reduction of erosion and trampling, as well as an increase in plant cover. During WY2012, watershed improvements were made to the West Fork of Chalone Creek; multiple structures were removed from the floodplain, the area was restored with native vegetation, and the new West Side Visitor Contact Station facilities were relocated outside of the floodplain. The mainstem of Chalone Creek was monitored during WYs 2011-2012, along with the Bear Gulch, McCabe Canyon, and Sandy Creek tributaries (Table 2 and Figure 3).

Table 2. Freshwater quality monitoring sites within Pinnacles National Park.

Site	Site Type	Flow Regime	Site Description
BG2	Primary	Perennial	Bear Gulch: directly upstream of footbridge, below Resource Management Office Building
CHA3	Secondary	Intermittent	North Fork Chalone Creek: upstream of North Wilderness Trail & Old Pinnacles Trail junction
CHA2	Primary	Perennial	Chalone Creek: upstream of Hwy146 Road bridge
CHA1	Primary	Perennial	Chalone Creek: off of the South Wilderness Trail
MC1	Primary	Perennial	McCabe Canyon: upstream of Hwy 146, across from the Pinnacles Campground
SC3	Secondary	Perennial	Sandy Creek: in Pinnacles Campground, down hill from campsite #1, in left bank channel
SC2	Secondary	Intermittent	Sandy Creek: in Pinnacles Campground, downstream of restrooms, across from campsite #68
SC1	Primary	Intermittent	Sandy Creek: opposite of the weather station pull-out on Hwy 146

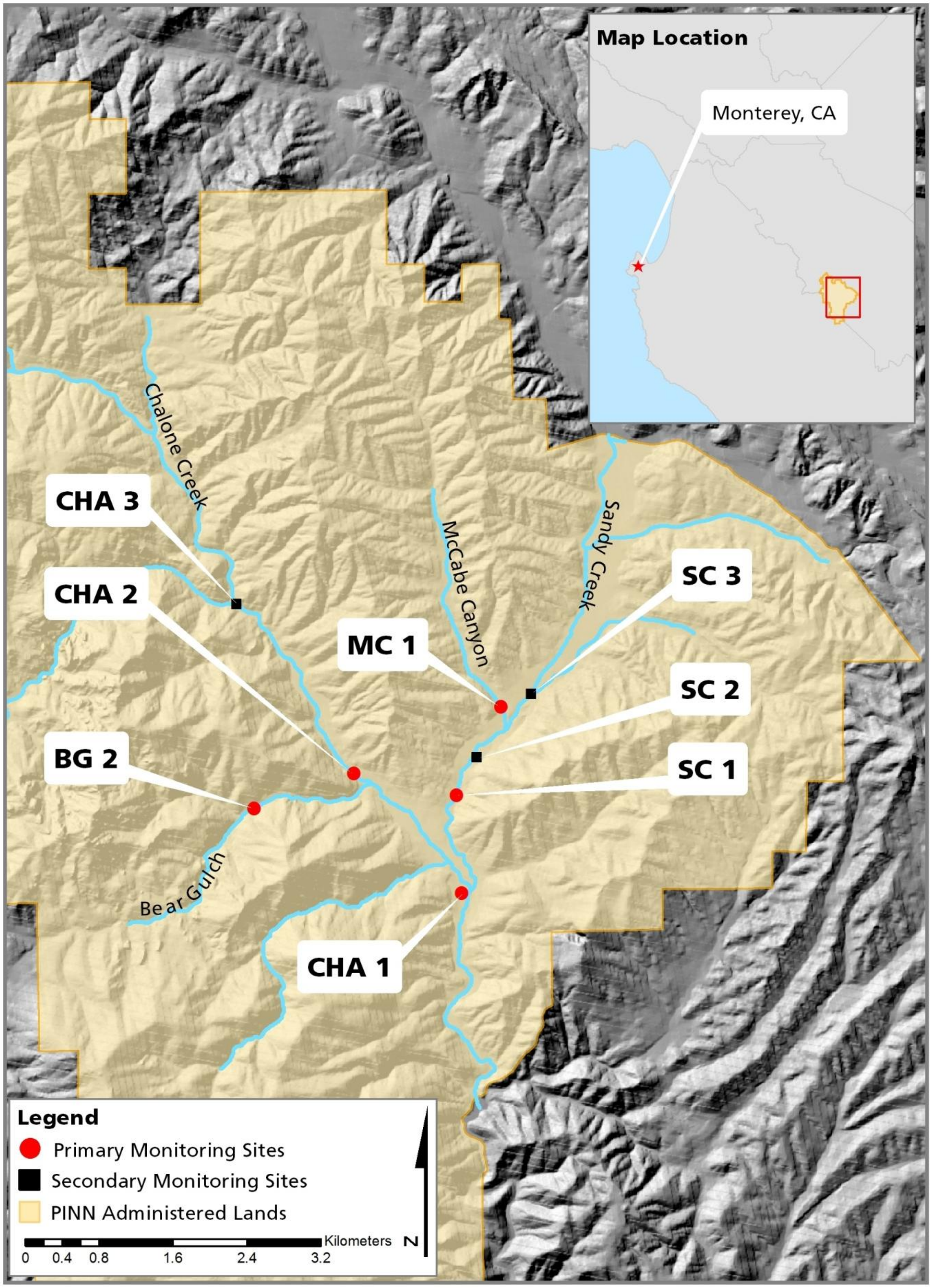

Figure 3. Freshwater quality monitoring sites within Pinnacles National Park.

Golden Gate National Recreation Area (GOGA)

During WYs 2011-2012, staff monitored seven GOGA sites as part of the SFAN Freshwater Quality sampling regime; these included two sites in the Rodeo Creek watershed, three in Tennessee Valley Creek, and one each in Oakwood and Nyhan Creeks (Table 3 and Figure 4). The Rodeo Creek watershed is approximately 4.4 mi^2 and empties into Rodeo Lagoon at Rodeo Beach in Fort Cronkhite (the southernmost portion of the Marin Headlands). The lagoon is infrequently connected to the ocean, and is not commonly affected by tidal influence. The Rodeo Creek headwaters are located almost entirely within GOGA lands in the Marin Headlands. Rodeo Creek is perennial, and is fed by Gerbode Creek and several small, unnamed tributaries. There are 20th century military buildings, park housing units, and a commercial horse stable, all located near the monitoring sites. The Tennessee Valley Creek watershed is approximately 2.4 square miles in size, and is situated north of the Rodeo Valley and south of the Redwood Creek watershed. Its headwaters are located entirely within GOGA lands. Tennessee Valley Creek flows northeast to southwest, and empties into the Pacific Ocean at Tennessee Cove. Developments in the watershed include a day-use parking lot and a commercial horse stable at the creek's headwaters. Adjacent to Tennessee Valley is the Oakwood Valley Creek watershed, which flows northwest along the eastern boundary of GOGA property until it joins Nyhan Creek (an approximately 2 square-mile watershed), just outside the park boundary. Nyhan Creek then flows east into Coyote Creek, and eventually to Richardson Bay and the San Francisco Bay.

Table 3. Freshwater quality monitoring sites within Golden Gate National Recreation Area.

Site	Site Type	Flow Regime	Site Description
RC1	Primary	Perennial	Rodeo Creek: across from Presidio Stables, 420 meters upstream of confluence with Gerbode Creek
GERB1	Primary	Perennial	Gerbode Creek: upstream of Bobcat Trail culvert, near Miwok Trail junction
OAK1	Secondary	Perennial	Oakwood Valley Creek: upstream end of culvert on east side of Tennessee Valley Road
NYH1	Primary	Perennial	Nyhan Creek: below footbridge on west side of Tennessee Valley Road
TV1	Secondary	Intermittent	Tennessee Valley Creek: in Miwok Stables area, above farthest upstream building (red house)
TV2	Primary	Intermittent	Tennessee Valley Creek: off of Tennessee Valley Trail, 330 meters upstream of Haypress tributary confluence
TV3	Primary	Intermittent	Tennessee Valley Creek: off of Tennessee Valley Trail, two meters downstream of Backdoor tributary

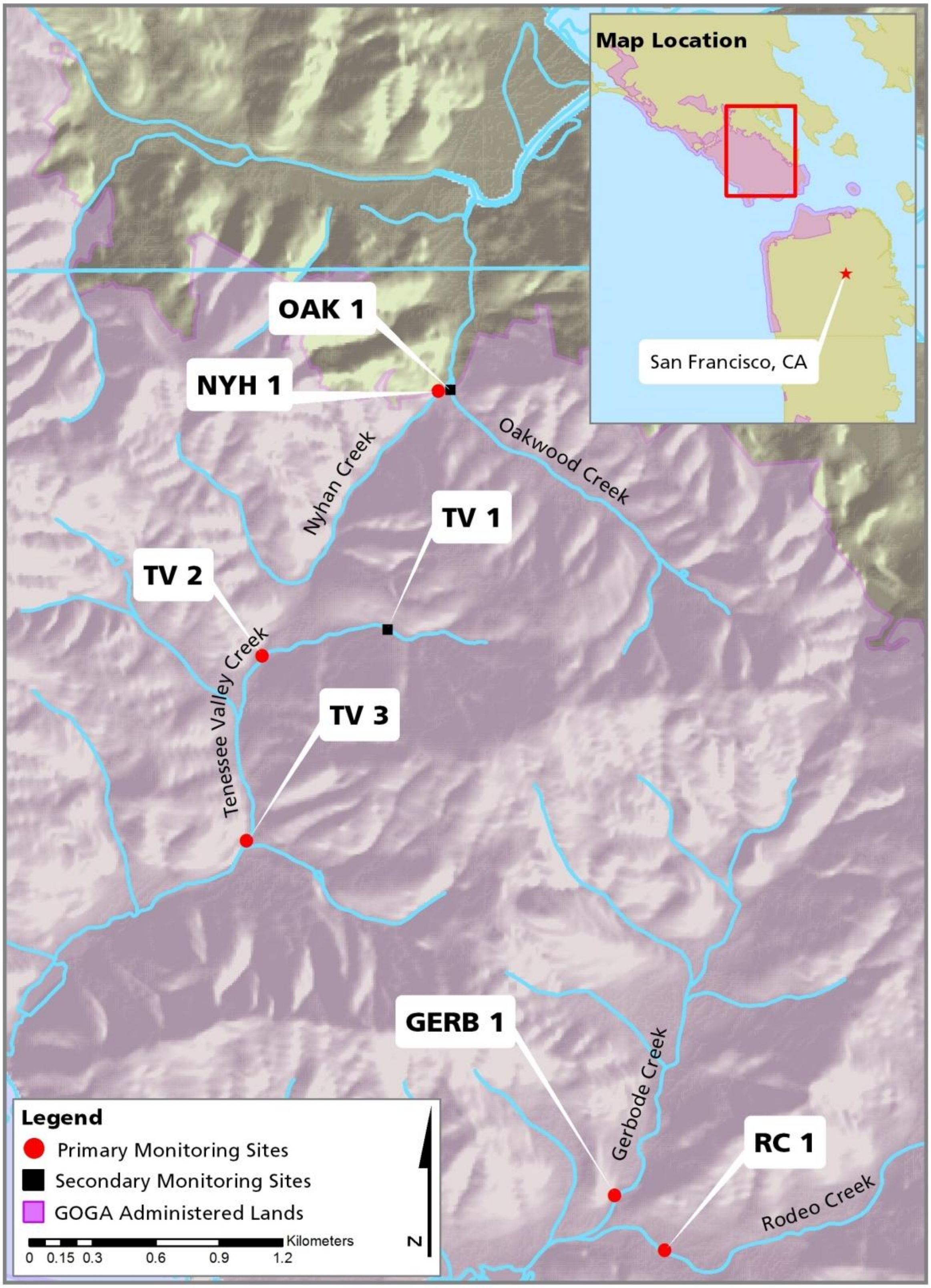

Figure 4. Freshwater quality monitoring sites within Golden Gate National Recreation Area.

John Muir National Historic Site (JOMU)

The Franklin Creek watershed is 3 square miles in extent and supports an intermittent stream that flows northward through JOMU west of the John Muir house. Downstream of the park boundary, Franklin Creek joins Alhambra Creek (also known as Arroyo del Hambre). Only 500 feet of Franklin Creek are on NPS property, so only one water quality monitoring site is located here. No water quality monitoring had been conducted at this site prior to the 2004 pilot sampling which helped to develop the SFAN Freshwater Quality Monitoring Protocol (Cooprider and Carson 2006). Steelhead have been observed in Franklin Creek, although the reach of creek in JOMU provides limited habitat for salmonids. On the opposite side of Hwy 4 the Strentzel Creek watershed drains the southwest side of Mount Wanda; approximately half of this watershed is on JOMU property. The Strentzel Creek watershed has significant erosion and sedimentation issues; these are a management priority for JOMU staff (Moore 2006). SFAN staff visit five secondary monitoring sites in this watershed during storm events (Table 4 and Figure 5). During WYs 2011-2012, two storm sampling events took place in the Strentzel Creek watershed; unfortunately, some of these sites did not have enough water and only sites STR3 and STR4 could be sampled.

Table 4. Freshwater quality monitoring sites within John Muir National Historic Site.

Site	Site Type	Flow Regime	Site Description
FRA1	Primary	Intermittent	Franklin Creek: downstream of footbridge, just upstream of gate & concrete ledge at northern end of park boundary
STR1	Secondary	Ephemeral	Strentzel Creek: above Strain Ranch, upstream of confluence with fourth north tributary (from east to west)
STR2	Secondary	Ephemeral	Fourth north tributary of Strentzel Creek
STR3	Secondary	Ephemeral	Third south tributary of Strentzel Creek
STR4	Secondary	Ephemeral	Strentzel Creek: mainstem Strentzel at first fire road crossing upstream of Strain Ranch
STR5	Secondary	Ephemeral	Strentzel Creek: mainstem Strentzel at Alhambra Ave. culvert

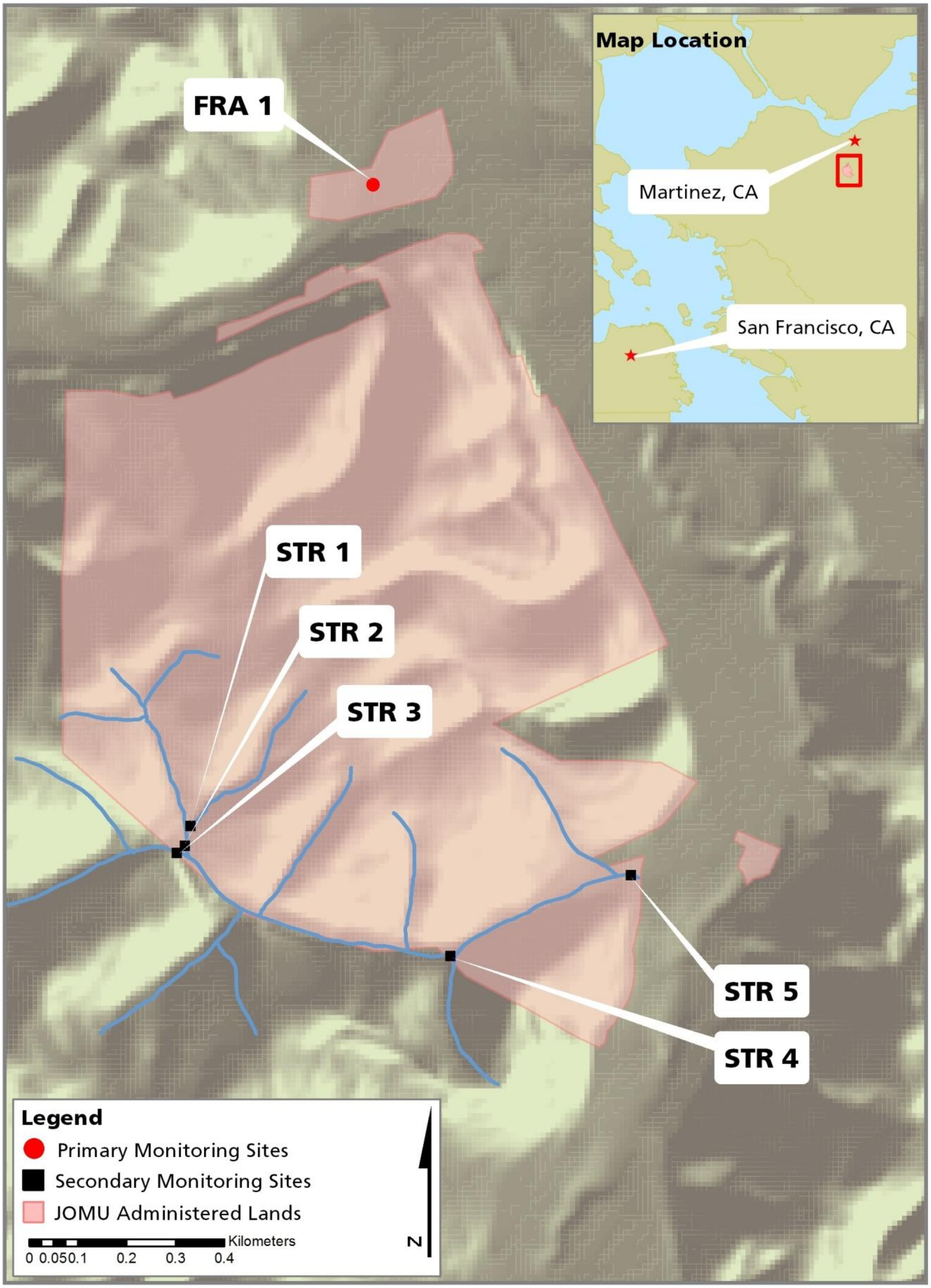

Figure 5. Freshwater quality monitoring sites within John Muir National Historic Site.

Methods

Water Quality Objectives

In California, the RWQCBs established Basin Plans, which set "numerical and narrative objectives for surface waters" (Tables 5, 6, & 7). The numerical objectives for bacteria are based on the national criteria established by the EPA (U.S. EPA 1986). Failure to meet water quality objectives (surpassing objective maximums) are referred to as exceedances throughout this report. The Basin Plans also outline the beneficial uses assigned to each stream that is a significant surface water feature. Although the San Francisco Bay RWQCB has identified some nutrients as impairments to Tomales Bay and is developing nutrient objectives for the region, objectives are currently not established for any nutrients except un-ionized ammonia. Only half of the SFAN freshwater quality parameters have established objectives put in place by the RWQCBs or the United States Environmental Protection Agency (EPA); other parameters (temperature, specific conductance, turbidity, and nitrate) do not have established objectives, and are compared to ecological objectives drawn from scientific literature.

Table 5. Numerical objectives for surface waters in PORE, GOGA, and JOMU - from the San Francisco Bay Regional Water Quality Control Board's Basin Plan (CA RWQCB 2010).

Parameter	Water Quality Objective
Dissolved oxygen (non-tidal waters, cold water habitat)	7.0 mg/L minimum
pH	Less than 8.5 and greater than 6.5 pH units

Table 6. Numerical objectives for surface waters in PINN - from the Central Coast Region Basin Plan (CA RWQCB 2011).

Parameter	Water Quality Objective
Dissolved Oxygen	5.0 mg/L minimum
pH	Less than 8.5 and greater than 7.0

Table 7. Pathogenic indicator bacteria water quality objectives for freshwater contact recreation use, from the San Francisco Bay Regional Water Quality Control Board's Basin Plan (CA RWQCB 2010).

Parameter	Objective Maximum
Total coliform	
Single-day sample	10,000
30-day average	1,000
Escherichia coli	
Single-day sample	235
30-day average	126
Fecal coliform	
Single-day sample	400
30-day average	200

In order to assist states with the development of nutrient standards, the EPA undertook nationwide sampling of nutrients in rivers and streams, and developed regional reference values (U.S. EPA 2000). The regional reference values can be used to assess whether nutrients in the SFAN are exceeding expected conditions. The EPA regional reference values for the sub-ecoregion encompassing the SFAN are 0.36 mg/L for total Kjeldahl nitrogen (TKN) and 0.16 mg/L for nitrate and nitrite (Table 8). Monitoring in the SFAN has shown nitrite values to be insignificant, thus the SFAN only samples nitrate (Cooprider 2004).

Table 8. Ecoregion III reference values for nutrients (U.S. EPA 2000).

Parameter	Regional Reference Value
Nitrate as nitrogen	0.16 mg/L
Nitrite as nitrogen	0.16 mg/L
Total Kjeldahl nitrogen	0.36 mg/L

Clean Water Act Section 303(d) Listed Waters

Water bodies within and adjacent to NPS lands have been listed under Section 303(d) of the Clean Water Act as impaired by pathogens, sediment, and nutrients. With the state as the lead in development of TMDLs, the NPS has participated as an active stakeholder, along with other partners, to support development and implementation of water quality monitoring and enhancement efforts in order to address water quality pollution issues.

In 2007, the San Francisco Bay RWQCB completed a TMDL project plan for pathogens in the Tomales Bay Watershed, which set forth water quality targets for Tomales Bay and its tributaries (CA RWQCB 2011). Part of this monitoring regime is conducted through the SFAN program in conjunction with the RWQCB and other stakeholders; this includes monthly monitoring of six SFAN sites along Olema Creek, in addition to intensive weekly monitoring for five consecutive weeks during both the winter and summer. Additional information about TMDLs in the SFAN can be found in the Freshwater Quality Monitoring Protocol (Cooprider and Carson 2006) and on the San Francisco Bay RWQCB's website (http://www.waterboards.ca.gov/sanfranciscobay/).

Site Selection

Detailed information about the process used to select SFAN monitoring locations is documented in the SFAN Freshwater Quality Monitoring Protocol (Cooprider and Carson 2006).

Sampling Regime

The sampling design for the SFAN Freshwater Quality Monitoring Program involves a rotating basin approach in which each watershed is monitored monthly for a two-year period (Table 9). This approach allows the SFAN to collect enough samples from each site and watershed in order to perform statistical analyses, while allowing for sufficient funds to perform laboratory analyses and provide representative data for each site. There are two groups of basins in this design, meaning that every four years, each site and each watershed group will have two years of data available for analysis. This design is intended to allow for the detection of both short- and long-term trends in all monitored watersheds. The only exception to the rotating basin approach is the Olema Creek watershed, which is monitored continuously, every year because sampling is mandated by a TMDL project. An effort is made to visit each site at approximately the same time of day, once per month (except for Strentzel Creek), and to attempt to capture one storm event per year.

Table 9. SFAN water quality monitoring schedule. (WY = water year, M = visited monthly, S = visited during at least one storm event, W = visited 5 consecutive weeks in the winter and summer as required by the Tomales Bay Pathogen TMDL Project.)

Watershed/Stream	Park Unit	WYs 2007-2008 & 2011-2012	WYs 2009-2010 & 2013-2014	Number of Monitoring Sites
Olema Creek	PORE	M, S, W	M, S, W	6 Primary
Pine Gulch	PORE	M		3 Primary
Franklin Creek	JOMU	M		1 Primary
Strentzel Creek	JOMU	S		0 Primary / 5 Secondary
Chalone Creek	PINN	M, S		5 Primary / 3 Secondary
Rodeo Creek	GOGA	M, S		2 Primary
Tennessee Creek	GOGA	M, S		2 Primary / 1 Secondary
Nyhan Creek	GOGA	M, S		1 Primary
Oakwood Creek	GOGA	M, S		0 Primary / 1 Secondary
West Union Creek	GOGA		M	2 Primary / 3 Secondary
Lagunitas Creek	PORE/GOGA		M, S	3 Primary
Redwood Creek	GOGA/MUWO		M, S	9 Primary / 2 Secondary

Primary sites ranked as a higher priority during site selection in the protocol development process, while secondary sites were identified to be of a slightly lower priority and could be integrated into the sampling regime only if funding and time allowed. Many of the secondary sampling sites are located in close proximity to primary sites, and it became apparent during the first year of monitoring that the sampling of core parameters and bacteria from the secondary sites could be conducted on each corresponding field day with little additional time. Furthermore, the SFAN acquired the IDEXX Quanti-Tray system for affordable (internal) processing of pathogenic indicator bacteria samples, which keeps costs low for the secondary sites. The processing of nutrient samples (by a contracted laboratory) is one of the largest costs to the SFAN water quality program; therefore, nutrient parameters are only monitored at primary sites.

Sample Parameters

The NPS I&M Program calls for monitoring of all basic level 1 water quality parameters. Level 1 parameters include a qualitative description of flow and core parameters (water temperature, dissolved oxygen, pH, and conductivity) (NPS 2002).

At each site, NPS staff measured core parameters in the field and collected grab samples for laboratory processing; staff also documented air temperature, cloud cover, flow severity, recent precipitation, and conducted photo monitoring (Table 10). Additionally, staff collected a quantitative discharge measurement at select sites (established stream gaging stations) when site conditions allowed, following methods set forth in the SFAN Streamflow Monitoring Protocol (Fong et al. 2011). All instantaneous measurements and grab samples were collected from the centroid of flow. Samples were analyzed for nutrients (nitrate as N and TKN [at primary sites only]), turbidity, and pathogenic indicator bacteria (total coliform and *Escherichia coli,* as well as fecal coliform in the Olema Creek watershed). All water quality sampling followed the methods described in the SFAN Freshwater Quality Monitoring Protocol (Cooprider and Carson 2006), manufacturer's equipment manuals, and U.S. Geological Survey (USGS) guidance.

Table 10. SFAN water quality monitoring parameters.

Parameter Group	Specific Parameters
Core	Water temperature, dissolved oxygen, pH, and conductivity
Bacteria	Total coliform & *E. coli* at all sites, fecal coliform at Olema Creek sites only
Sediment	Turbidity
Nutrients	Total Kjeldahl nitrogen (TKN) and nitrate (as N)
Discharge	Qualitative flow description (& quantitative stream discharge at select sites)

Table 11 lists the processing methods used for all parameters. NPS staff collected core parameter data in-situ, using a YSI ProPlus (Professional Series) multiprobe sonde. In order to evaluate samples for fecal coliform concentration (at Olema Creek watershed sites only), the RWQCB contracted with CEL Analytical Laboratory in San Francisco to conduct analyses. NPS staff installed the IDEXX Quanti-Tray system at PORE's Pacific Coast Science and Learning Center in January 2007; NPS staff processed all total coliform, *E. coli*, and turbidity samples at this location. Analytical Sciences LLC, in Petaluma, CA processed all nutrient samples.

Table 11. Water quality testing methods used in the SFAN.

Parameter	Method
Core parameters	Instantaneous readings collected in the centroid of flow with a multiprobe sonde.
Total coliform bacteria	Enzyme substrate coliform test: standard method 9223B using IDEXX Quanti-Tray 2000 with colilert reagent
E. coli bacteria	Enzyme substrate coliform test: standard method 9223B using IDEXX Quanti-Tray 2000 with colilert reagent
Fecal coliform bacteria	Fecal coliform by multiple tube fermentation: standard method 9221B
Nitrate (as N)	EPA method 300 [detection limit: 0.15 mg/L]
TKN	Standard method 4500-Norg C [detection limit: 0.25 mg/L]
Turbidity	Hach 2100P turbidimeter
Discharge	Methods from the SFAN Streamflow Monitoring Protocol, using a SonTek FlowTracker ADV, Marsh-McBirney Flowmate, or volumetric discharge method (Fong et al. 2011).

Data Handling and Analysis

NPS staff entered all data into NPSTORET (housed at PORE), which is the database created and provided by the NPS Water Resources Division. All data that were entered into NPSTORET were verified by an alternate staff person. These data are periodically uploaded to the EPA STORET database that allows for public access.

Water quality data contain many values that can not be quantified, but are known to be above or below a certain threshold (e.g., reporting limit, detection limit, quantification limit, etc.); these data are considered censored during statistical analysis (Helsel 2005). The SFAN nutrient results are often reported as "non-detect", meaning that the value is not defined as zero, but is only known to be less than the reporting detection limit of that particular method. The SFAN bacteria results can be censored on either end (producing results above or below the quantifiable range), which further complicates data analysis. A study by the USGS (Antweiler and Taylor 2008) evaluated the main classes of statistical treatment of censored environmental data, and found that the nonparametric Kaplan-Meier method was the most effective technique for overall determination of summary statistics for datasets with less than 70% censoring; the Kaplan-Meier statistical method was used (through the NPSTORET database) to create summary statistics and figures for all censored SFAN data.

Quality Control

NPS staff calibrated field equipment at the beginning of each sampling day, performing a three-point calibration for all pH sensors, a one-point calibration for conductivity (specific conductance), and the water-saturated air method (one-point calibration) for dissolved oxygen. NPS staff performed calibration checks immediately following each calibration, and again at the end of the field day, in order to monitor for fouling and drift, and to ensure that the instruments stayed within the calibration acceptance criteria of each parameter. If any parameter failed a post-field drift check, all corresponding results from that entire field day were thrown out.

In order to assess precision, approximately 10% of all samples were collected in duplicate. Additionally, trip blanks (distilled water) were collected and submitted for laboratory analysis, in order to detect and locate possible sources of contamination. Laboratory quality control (QC) measures included matrix spikes, method blanks, laboratory control spikes and use of a variety of calibration standards.

Measurement Quality Objectives

The SFAN has established measurement quality objectives (MQOs) for all monitored parameters. There are MQOs for calibration acceptance, precision, and systematic error (percent recovery). Measurement of systematic error (reported as percent recovery) represents the accuracy of the laboratory procedures and equipment, which is determined by conducting matrix spikes or laboratory control spikes, to test a known value of a particular analyte. The MQO for systematic error (percent recovery) is 70-130% for TKN, and 75-125% for nitrate (as N). During WYs 2011-2012, the professional laboratory contracted by the SFAN did not report any QC results that were outside of these acceptable ranges.

The MQOs for precision are defined in the SFAN Freshwater Quality Monitoring Protocol as the acceptable thresholds of relative percent difference (RPD), calculated from the duplicated QC sample sets. The precision MQO for nitrate (as N) and TKN is +/- 30% (RPD), while the MQO for total coliform and fecal coliform is +/- 60% (RPD); an MQO was not established for *E. coli*, but it can be assumed to be 60% as well.

A total of 287 duplicate QC samples were collected during WYs 2011-2012; 19% of these (54 of 287) included a censored result which prevented calculation of RPD/precision. Because of this limitation, Table 12 contains the mean RPD values (for each parameter) calculated only from those QC tests that had quantifiable RPD (did not include a censored result). The only parameter that did not produce any precision MQO failures was nitrate (as N); no nitrate duplicate had an RPD above 30%, and the mean RPD of all QC tests was only 4.27%. The TKN results also had a low mean RPD (8.44%), well below the precision MQO. The mean RPD values for the total coliform and *E. coli* QC tests were much higher (28.66% and 44.32%, respectively), but were still well below their specific MQO of +/- 60%. The fecal coliform QC tests (all run by a contracted laboratory) produced a mean RPD of 47.91%, also below the acceptable threshold of 60%.

Table 12. Precision of SFAN nutrient and bacteria samples during water years 2011-2012. (QC = quality control; RPD = relative percent difference; MQO = measurement quality objective)

	Nitrate as Nitrogen (mg/L)	**Total Kjeldahl Nitrogen (mg/L)**	**Total Coliform (MPN/100mL)**	***Escherichia coli* (MPN/100mL)**	**Fecal Coliform (MPN/100mL)**
Total Number of QC Duplicates	53	53	75	75	31
Number of QC Dups with Measurable RPD[1]	18	50	69	65	31
Number that Failed to Meet MQO for RPD[1]	0	1	7	21	9
Mean RPD[1] (Precision)	4.27%	8.44%	28.66%	44.32%	47.91%
SFAN MQO for RPD (Precision)	**+/- 30%**	**+/- 30%**	**+/- 60%**	**+/- 60%**	**+/- 60%**

[1] Many duplicate QC measurements (19% of 287) did not have measurable RPD because of a censored result; therefore, the calculated mean RPD values and number of failures do not include all duplicate QC measurements collected during WYs 2011-2012.

Results and Discussion

This report includes results collected from October 1, 2010 through September 30, 2012 (WYs 2011-2012), the fifth and sixth years of protocol implementation. Due to the two-year rotating basin design of this protocol, the WY 2011 and 2012 data represent the third and fourth years of monitoring this specific set of sites (nine sites in PORE, eight in PINN, seven in GOGA, and six in JOMU). While it is not yet possible to observe long-term trends, the data can be viewed in the context of established water quality objectives, ecological objectives, and regional reference values established by the EPA.

Routine monitoring visits took place monthly, at approximately the same time of day, and an effort was made to collect storm samples from every site during each water year. Storm sampling was conducted in each park during WY 2011, and again in each park (except for PINN) during WY 2012. Only two sites in JOMU's Strentzel Creek watershed (STR3 and STR4) had adequate flow and were able to be sampled during both storm sampling events. Some sites exhibited intermittent seasonal flow patterns, and were recorded as "dry" or "no flow" on routine monthly visits during WYs 2011-2012. Three sites in PINN (CHA3, SC2, and SC1) and three sites in GOGA (OAK1, TV1, and TV2) were too low for sampling at least once during the dry seasons, so their summary statistics are computed from smaller datasets. The six Olema Creek watershed sites (in PORE) have the largest datasets, due to the additional monitoring required by the San Francisco Bay RWQCB's Tomales Bay Pathogen TMDL Program.

Summary statistics for WYs 2011-2012 are presented in the following sections, organized by parameter and park. Sites with fewer than four results (STR3 and STR4) are included in the summary tables, but are excluded from the figures since their datasets are too small for analysis (U.S. EPA 1998). All calculations, results, and statistics discussed in this report are from these two water years as a whole, not individually. All means and standard deviations presented in tables are rounded to one more decimal place than the least precise value (fewest number of decimal places) of each corresponding dataset (Sullivan 2011).

Core Parameters

Water temperature, dissolved oxygen, pH, and conductivity (specific conductance) are defined as core parameters in the SFAN Freshwater Quality Monitoring Protocol; these are all interrelated, and describe the most basic level of water chemistry. Thorough knowledge of core parameters is needed in order to better understand nutrient and bacteria data collected; therefore, these parameters are measured in-situ during every site visit, alongside each grab sample collection.

Summary statistics of all core parameter results from WYs 2011-2012 are displayed in detail in Tables 13, 14, 15, and 16; however, box and whiskers plots of these data are displayed separately (sorted by parameter) for simplified viewing. Turbidity data are included at the end of this section, although not defined as a core parameter in the SFAN Protocol. All summary statistics are based on instantaneous measurements routinely collected at approximately the same time of day on each visit; therefore, the data in the tables and figures presented do not reflect the true minimum and maximum values of diel variation.

Table 13. Core parameter results from Point Reyes National Seashore (water years 2011-2012). (Std. dev. = standard deviation. N of obs. = number of observations.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	OLM18	OLM1	OLM14	OLM6A	OLM11	OLM10B	PNG3	PNG2	PNG1
Water temperature (°C)	Mean	10.66	11.32	11.05	11.14	11.99	11.59	11.18	11.17	11.62
	Median	10.7	11.2	10.9	11.7	12.1	12.1	11.8	11.7	12.3
	Minimum	3.9	4.1	3.2	3.9	3.6	2.7	7.0	7.2	8.3
	Maximum	13.7	14.6	14.3	13.8	16.2	15.8	14.8	14.9	15.0
	Std. dev.	2.43	2.68	2.84	2.31	3.34	3.26	2.15	2.15	2.04
	N of obs.	41	41	41	41	41	41	24	24	24
Dissolved oxygen (mg/L)	Mean	8.496	9.151	10.110	10.840	10.110	9.016	10.550	10.430	9.907
	Median	9.36	9.95	10.39	10.74	10.00	9.21	10.60	10.37	10.10
	Minimum	3.01	4.87	7.49	9.84	8.35	5.55	9.34	9.33	7.86
	Maximum	10.90	11.43	12.25	13.17	13.56	12.35	12.37	12.38	12.19
	Std. dev.	1.935	1.924	1.297	0.740	1.213	1.676	0.749	0.744	1.080
	N of obs.	40	40	40	40	40	40	24	24	24
pH (pH units)	Mean	6.891	7.161	7.588	8.029	7.666	7.501	7.783	7.624	7.534
	Median	6.82	7.16	7.64	8.08	7.71	7.48	7.80	7.64	7.56
	Minimum	6.53	6.66	6.82	7.34	6.97	6.89	7.54	7.34	7.10
	Maximum	7.39	7.45	7.85	8.19	7.93	7.81	7.92	7.81	7.79
	Std. dev.	0.247	0.176	0.206	0.199	0.202	0.146	0.091	0.109	0.145
	N of obs.	41	41	41	41	41	41	23	23	23
Specific conductance (µS/cm)	Mean	122.80	147.10	205.50	254.80	227.80	237.50	207.80	200.70	212.50
	Median	125.9	142.0	193.5	262.6	236.9	232.0	214.0	197.1	212.8
	Minimum	86.2	79.6	101.2	167.4	99.9	110.8	150.8	146.1	133.2
	Maximum	152.2	209.0	300.8	317.1	327.7	418.5	245.2	254.5	272.2
	Std. dev.	19.53	36.95	61.74	44.14	63.99	67.82	28.65	36.28	40.83
	N of obs.	37	37	37	37	37	37	24	24	24
Turbidity (NTU)	Mean	9.91	12.8	18.5	8.2	20.4	13.4	2.306	2.716	2.83
	Median	4.57	1.67	1.66	2.59	1.68	3.14	1.22	1.64	1.65
	Minimum	0.93	0.37	0.47	0.95	1.05	1.35	0.49	0.65	0.58
	Maximum	67.1	241	372	151	391	170	9.97	9.79	13.5
	Std. dev.	13.76	40.2	61.3	23.7	67.1	31.3	2.422	2.430	3.22
	N of obs.	41	41	41	41	41	41	24	24	24

Table 14. Core parameter results from Pinnacles National Park (water years 2011-2012). (Std. dev. = standard deviation. N of obs. = number of observations.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	BG2	CHA3	CHA2	CHA1	MC1	SC3	SC2	SC1
Water temperature (°C)	Mean	12.26	10.61	12.22	14.33	15.18	13.72	10.78	12.86
	Median	11.7	10.0	11.3	14.8	15.2	15.0	10.5	13.8
	Minimum	7.0	6.1	5.3	10.7	7.7	6.8	3.1	4.6
	Maximum	16.3	17.0	16.1	16.9	21.7	18.7	18.1	19.6
	Std. dev.	2.69	3.13	2.74	1.78	3.97	3.32	3.98	4.21
	N of obs.	24	13	24	24	24	24	19	18
Dissolved oxygen (mg/L)	Mean	7.071	6.743	7.854	4.605	9.182	9.172	3.753	10.510
	Median	7.43	7.22	7.55	4.20	9.06	9.19	3.67	10.29
	Minimum	3.39	0.84	6.74	0.80	7.56	7.46	0.90	8.01
	Maximum	11.66	12.14	11.35	11.05	10.99	10.75	6.75	14.15
	Std. dev.	2.105	3.739	1.139	2.589	0.975	0.781	1.685	1.887
	N of obs.	24	13	24	24	24	24	19	18
pH (pH units)	Mean	7.258	7.316	7.394	7.050	7.838	8.088	7.341	8.215
	Median	7.24	7.31	7.38	7.04	7.82	8.08	7.39	8.27
	Minimum	6.73	6.84	7.21	6.82	7.67	7.93	7.04	7.59
	Maximum	7.63	7.85	7.68	7.50	8.35	8.19	7.77	8.60
	Std. dev.	0.219	0.267	0.111	0.150	0.155	0.062	0.187	0.241
	N of obs.	21	10	21	21	21	21	16	15
Specific conductance (µS/cm)	Mean	258.50	355.40	324.20	502.00	217.60	794.20	952.30	717.50
	Median	303.4	353.4	340.4	510.3	209.9	815.0	967.0	780.0
	Minimum	36.0	167.0	69.6	92.0	140.1	343.0	395.0	285.0
	Maximum	365.1	434.9	511.2	700.0	344.9	1033.0	1198.0	953.0
	Std. dev.	93.30	68.87	118.60	153.40	60.65	177.90	181.80	215.80
	N of obs.	23	12	23	23	23	23	18	17
Turbidity (NTU)	Mean	3.25	3.14	1.48	5.63	83.5	2.070	3.69	27.91
	Median	1.26	1.27	0.66	1.65	80.3	1.89	2.34	20.9
	Minimum	0.31	0.52	0.22	0.50	55.4	0.41	1.05	2.05
	Maximum	25.7	15.4	14.6	40.5	145	5.93	11.5	72.6
	Std. dev.	5.30	4.20	2.90	9.36	23.4	1.299	3.05	16.36
	N of obs.	24	13	24	24	24	24	19	17

Table 15. Core parameter results from Golden Gate National Recreation Area (water years 2011-2012). (Std. dev. = standard deviation. N of obs. = number of observations.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	RC1	GERB1	OAK1	NYH1	TV1	TV2	TV3
Water temperature (°C)	Mean	10.38	10.25	11.55	11.65	11.08	11.78	11.27
	Median	10.3	10.1	11.8	12.8	11.4	11.7	11.5
	Minimum	5.3	5.1	8.2	6.2	7.9	9.3	6.8
	Maximum	13.4	13.3	14.2	15.0	13.3	17.2	14.0
	Std. dev.	2.29	2.35	2.05	2.66	1.50	2.14	2.20
	N of obs.	24	24	22	24	12	20	24
Dissolved oxygen (mg/L)	Mean	9.521	9.883	7.864	8.739	10.220	6.039	9.147
	Median	9.38	9.98	8.74	9.41	10.64	7.79	9.46
	Minimum	6.90	8.43	2.06	5.80	7.94	0.22	5.47
	Maximum	11.45	11.78	10.84	11.16	11.18	10.39	11.43
	Std. dev.	1.409	1.092	2.697	1.867	0.869	3.815	1.785
	N of obs.	23	23	21	23	12	19	23
pH (pH units)	Mean	7.513	7.423	7.167	7.690	7.469	6.952	7.437
	Median	7.41	7.40	7.22	7.69	7.44	6.86	7.41
	Minimum	7.20	6.96	6.44	7.50	7.14	6.57	7.15
	Maximum	8.22	7.97	7.72	7.94	7.76	7.65	7.80
	Std. dev.	0.248	0.206	0.360	0.123	0.184	0.333	0.175
	N of obs.	23	23	21	23	11	19	23
Specific conductance (µS/cm)	Mean	220.30	164.40	298.00	359.90	113.20	297.00	196.70
	Median	227.3	171.0	312.9	344.6	107.5	262.3	202.5
	Minimum	155.8	108.5	163.8	160.6	87.8	128.1	126.8
	Maximum	281.3	214.2	440.8	574.1	148.5	655.0	265.5
	Std. dev.	36.14	32.92	85.57	112.70	22.46	175.80	41.34
	N of obs.	23	23	21	23	11	19	23
Turbidity (NTU)	Mean	15.43	14.61	10.87	8.72	16.69	56.4	16.13
	Median	9.70	9.15	1.96	2.26	13.6	14.6	7.05
	Minimum	5.91	5.19	0.29	0.89	5.21	5.52	4.93
	Maximum	53.3	46.3	85.4	55.1	38.5	493	86.2
	Std. dev.	11.96	11.15	21.57	14.77	11.41	119.6	18.92
	N of obs.	24	24	22	24	12	20	24

Table 16. Core parameter results from John Muir National Historic Site (water years 2011-2012). (Std. dev. = standard deviation. N of obs. = number of observations.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	FRA1	STR3	STR4
Water temperature (°C)	Mean	12.65	-	-
	Median	12.6	-	-
	Minimum	6.3	9.6	9.1
	Maximum	17.9	12.2	11.6
	Std. dev.	3.32	-	-
	N of obs.	22	2	2
Dissolved oxygen (mg/L)	Mean	10.030	-	-
	Median	10.19	-	-
	Minimum	6.86	8.67	8.69
	Maximum	12.45	10.23	9.99
	Std. dev.	1.360	-	-
	N of obs.	22	2	2
pH (pH units)	Mean	8.089	-	-
	Median	8.10	-	-
	Minimum	7.81	7.89	7.80
	Maximum	8.29	7.93	7.80
	Std. dev.	0.125	-	-
	N of obs.	22	2	2
Specific conductance (µS/cm)	Mean	1214.00	-	-
	Median	1309.0	-	-
	Minimum	635.4	271.40	415.2
	Maximum	1514.0	526.9	574.1
	Std. dev.	251.30	-	-
	N of obs.	21	2	2
Turbidity (NTU)	Mean	20.5	-	-
	Median	1.30	-	-
	Minimum	0.4	39.0	45.8
	Maximum	231	41.5	95.9
	Std. dev.	53.5	-	-
	N of obs.	22	2	2

Water Temperature

There is not an established water quality objective for water temperature in SFAN streams, so criteria for salmonids are often considered as ecological objectives. The water temperature range for optimal growth of juvenile coho is 10 to 15.6°C (Armour 1991); although salmonids have various temperature requirements during different life history stages and seasons, this range is used as a guideline when reviewing the SFAN water temperature results. During WYs 2011-2012 mean water temperatures were within this optimal range at every SFAN site, and all results were below 25°C, a temperature known to be lethal to juvenile coho (Moyle 2002). Every site produced at least one result below the optimal range (less than 10°C), except for CHA1 in PINN, which had one of the highest mean temperatures.

Of all sites monitored during WYs 2011-2012, the PORE sites are the only ones that support known populations of coho and steelhead. Only 2% of PORE results (6 of 318) exceeded the upper end of the optimal range (15.6°C) and these were all from the two farthest downstream Olema Creek sites, OLM11 and OLM10B (Figure 6). The highest mean temperatures in the SFAN were found at FRA1 (in JOMU) and six of the PINN sites. The PINN sites exhibited the widest range of results and the majority of the highest water temperature recordings in the SFAN (Figure 7). Twenty-two percent of PINN results (37 of 170), and 19% of JOMU results (5 of 26), exceeded the upper end of the optimal range (15.6°C); in contrast, less than one percent of the GOGA results (1 result of 150) surpassed this level (Figures 8 and 9).

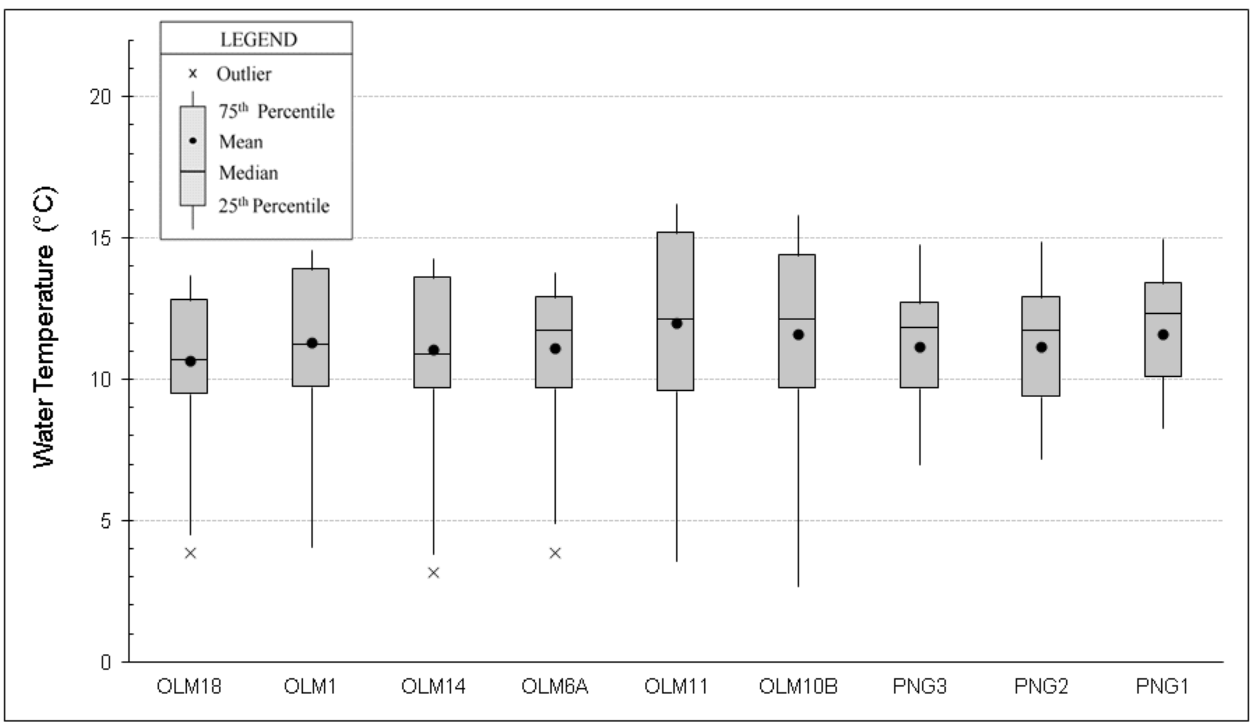

Figure 6. Water temperature results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

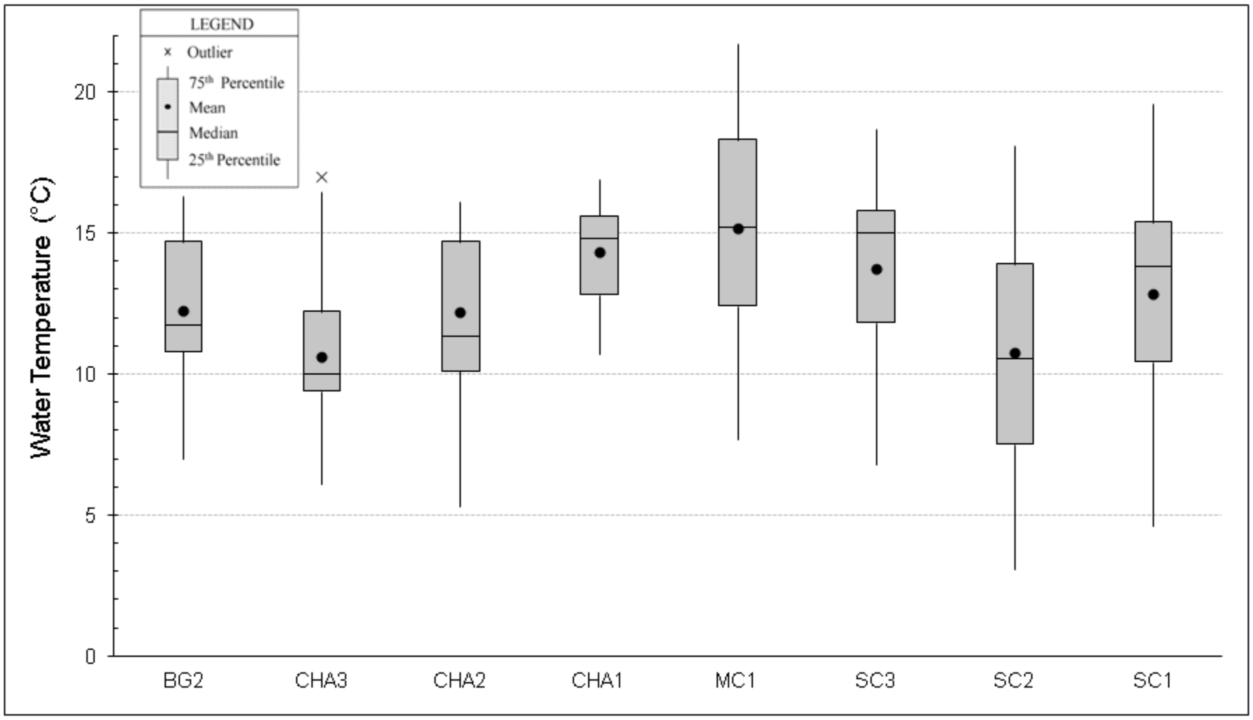

Figure 7. Water temperature results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

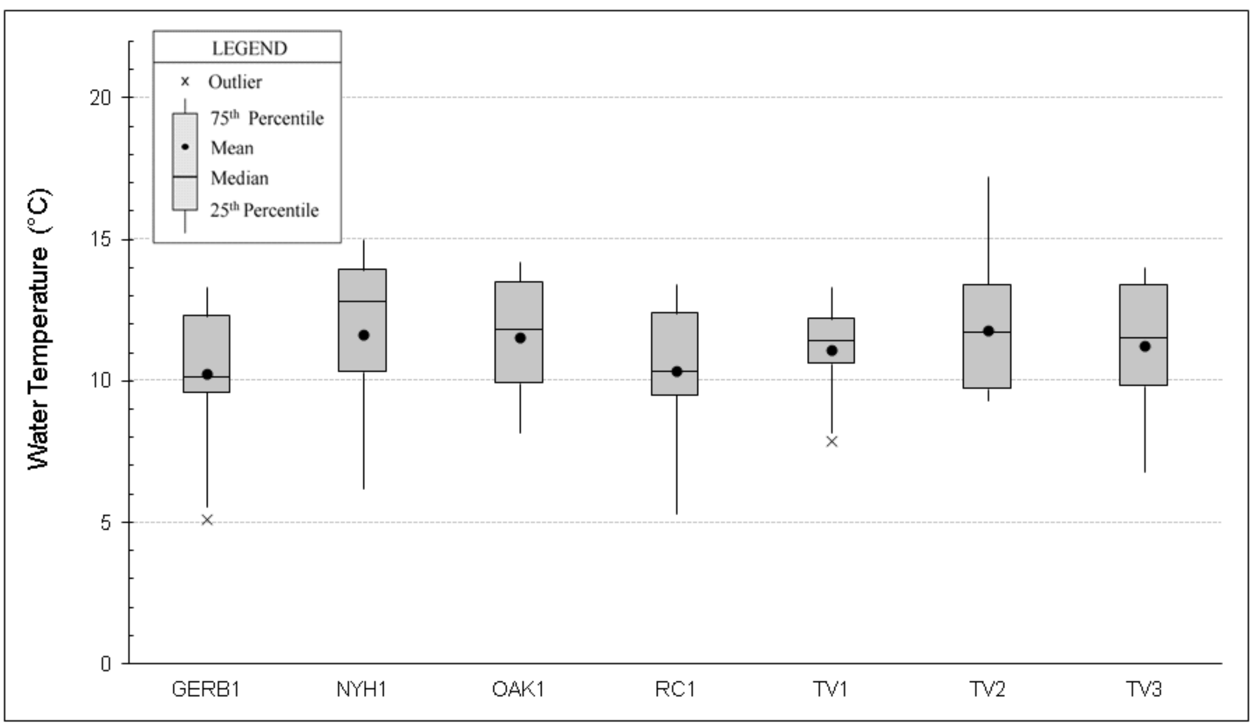

Figure 8. Water temperature results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

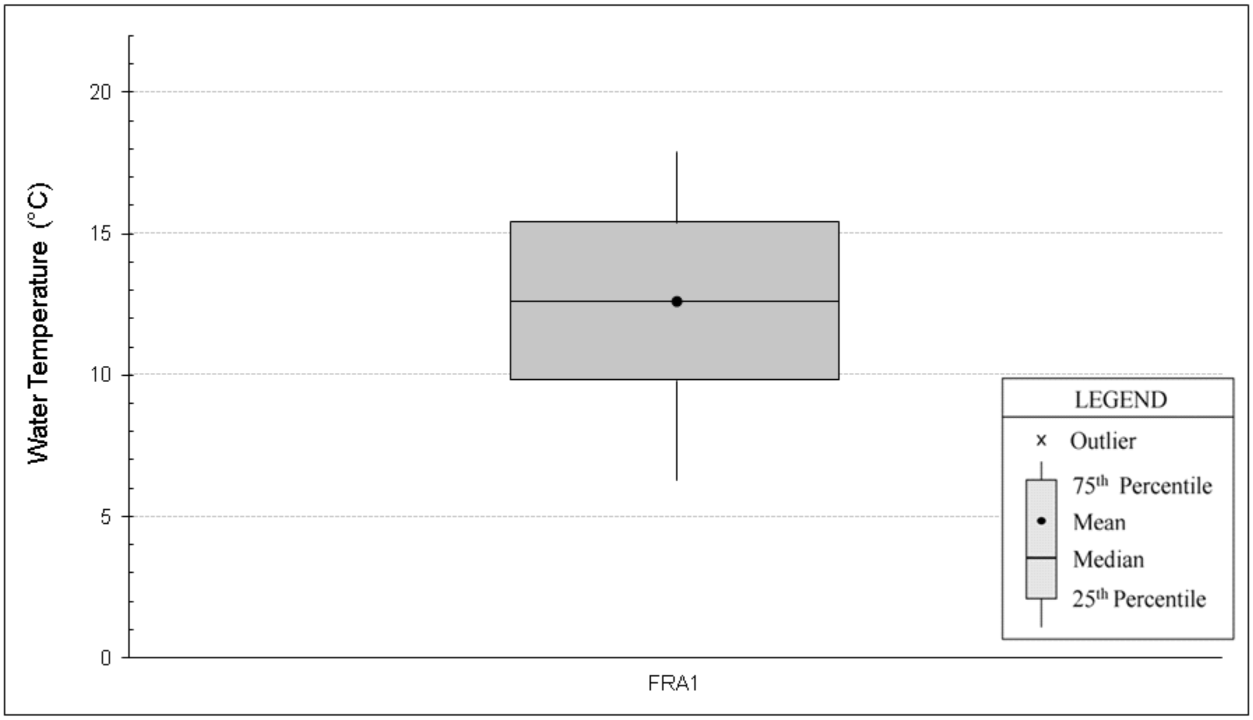

Figure 9. Water temperature results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

Dissolved Oxygen

The San Francisco Bay RWQCB established a dissolved oxygen minimum of 7 mg/L, which applies to PORE, GOGA, and JOMU. This threshold is particularly important to the Pine Gulch and Olema Creek watershed sites in PORE, because they still support salmonid populations. A dissolved oxygen minimum of 5 mg/L (established by the Central Coast RWQCB) applies to the eight PINN sites. During WYs 2011-2012, 14% of all SFAN dissolved oxygen results (91 of 652) failed to meet their respective objectives; the majority of these failures were from PINN sites. Dissolved oxygen means were above the water quality objectives for every SFAN site, except for SC2 and CHA1 (PINN sites).

Seven percent of all PORE results (23 of 312) fell below the dissolved oxygen minimum objective of 7 mg/L; these low levels were only found at three specific sites (OLM18, OLM1, and OLM10B) and all were recorded during low flow conditions in late summer or early fall. The other half of the Olema Creek watershed sites (OLM14, OLM6A, and OLM11), along with the three Pine Gulch watershed sites (PNG1, PNG2, and PNG3), consistently demonstrated high dissolved oxygen levels (no readings below the minimum objective) during WYs 2011-2012 (Figure 10). In contrast, the PINN dataset had the highest failure rate in the SFAN (when compared to the lower minimum objective of 5 mg/L). Twenty-four percent of the PINN results (41 of 170) failed to meet this objective during WYs 2011-2012; however, all of these low levels were found at four sites, while the other half of the sites (CHA2, MC1, SC3, and SC1) exhibited consistently high dissolved oxygen readings during each monthly visit of WYs 2011-2012 (Figure 11).

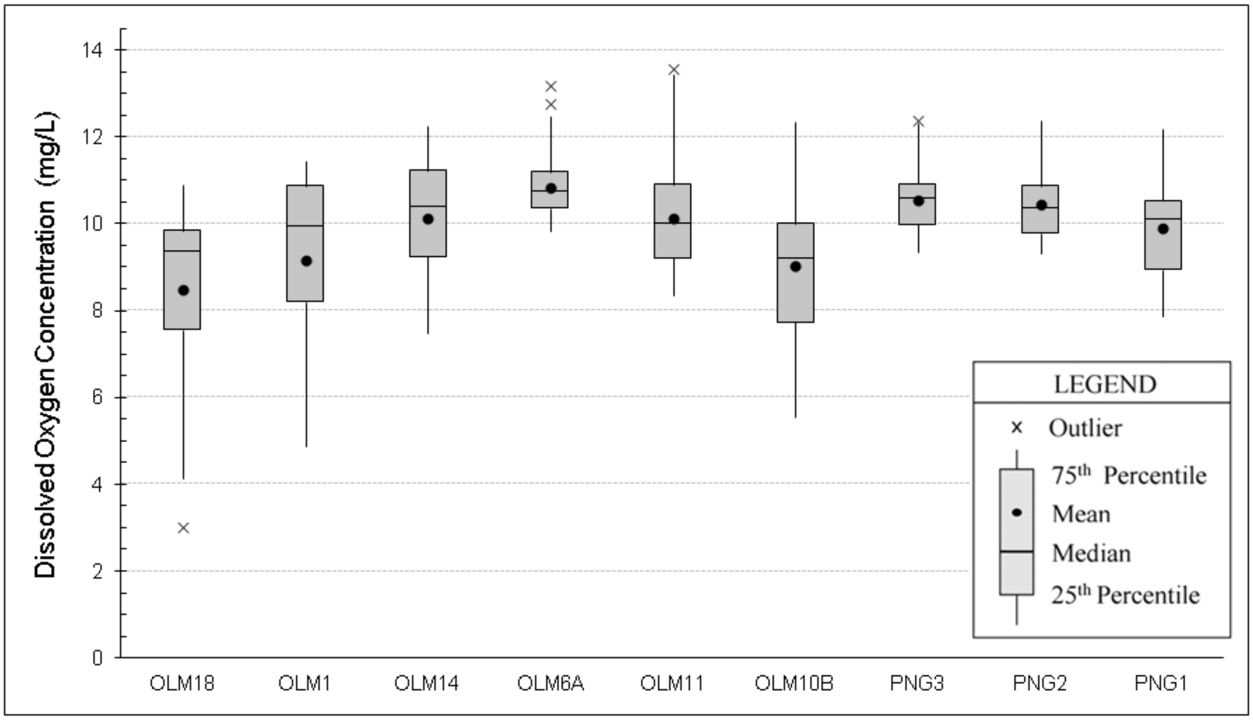

Figure 10. Dissolved oxygen results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

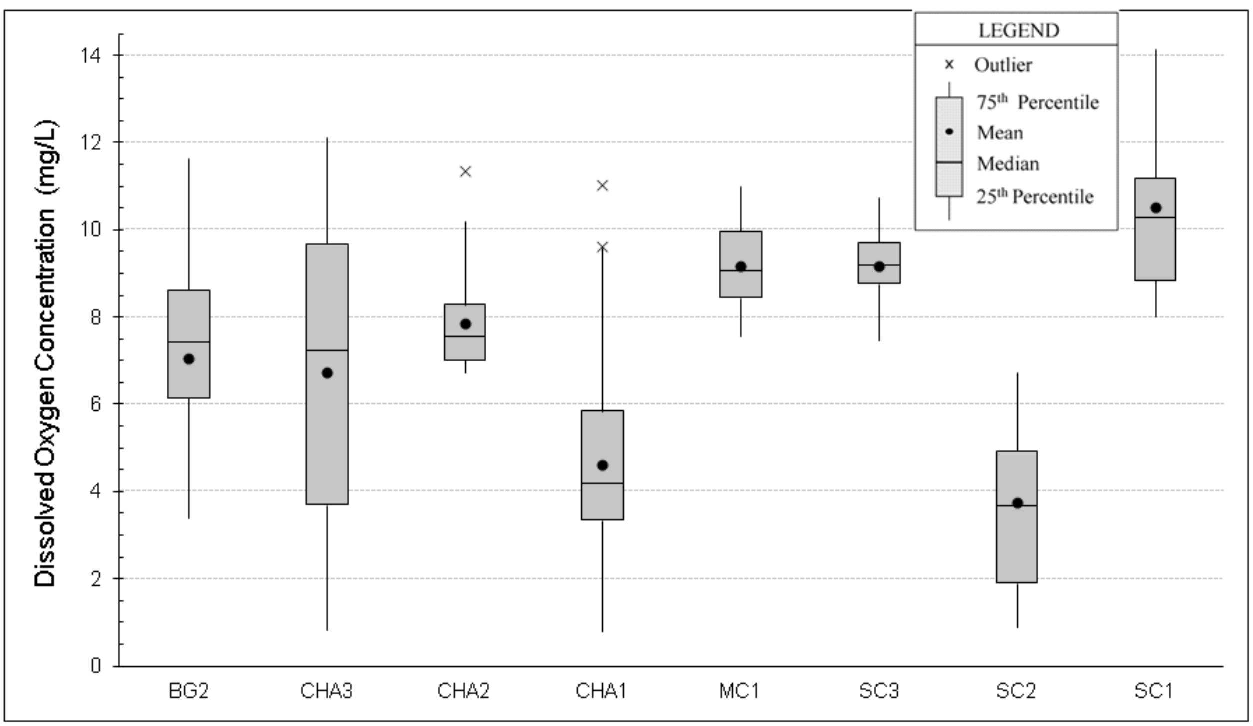

Figure 11. Dissolved oxygen results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

The GOGA sites also had many low dissolved oxygen readings; 18% of all GOGA results (26 of 144) failed to meet the minimum objective of 7 mg/L during WYs 2011-2012. All of these low levels were recorded at five of the GOGA sites, usually during late summer and early fall; two GOGA sites (GERB1 and TV1) had consistently high levels (above the dissolved oxygen minimum objective) on each site visit (Figure 12). Site TV2, in Tennessee Valley Creek, produced the lowest mean of these seven GOGA sites (6.039 mg/L), the lowest dissolved oxygen recording on nearly every GOGA sampling day, and the two lowest individual measurements collected in the entire SFAN Freshwater Quality Program during WYs 2011-2012 (0.22 and 0.61 mg/L).

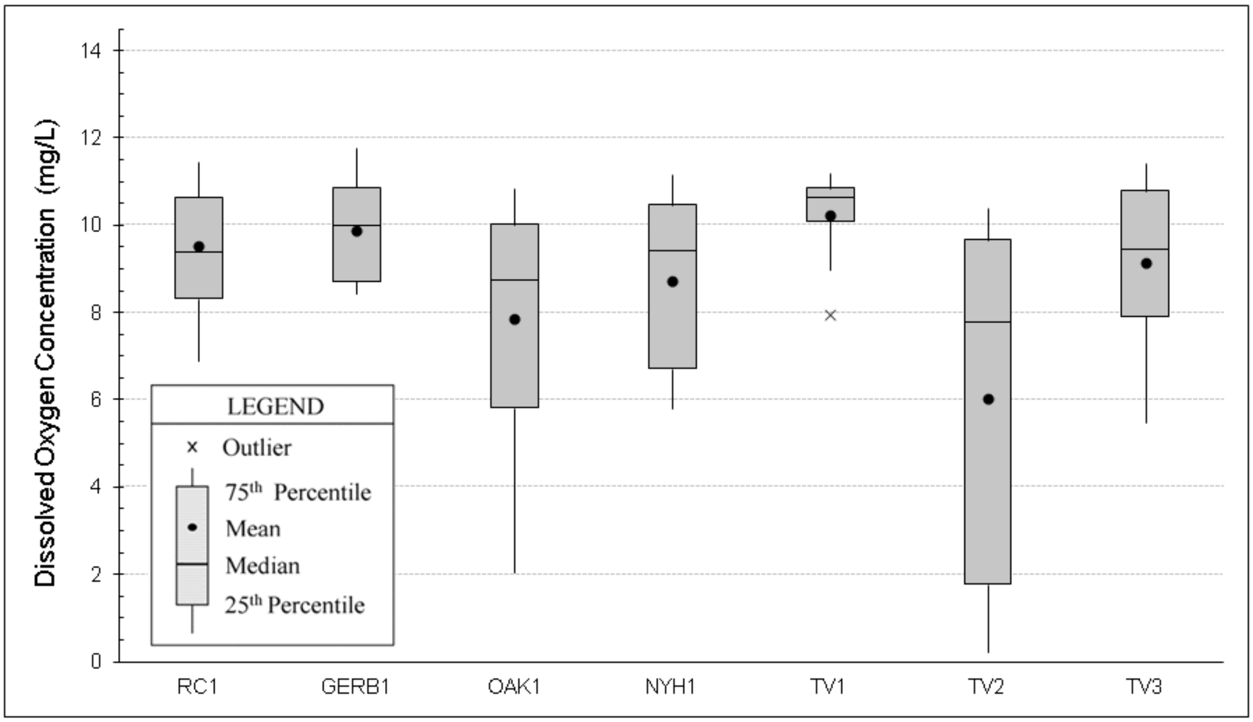

Figure 12. Dissolved oxygen results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

A total of 26 dissolved oxygen measurements were collected from JOMU during WYs 2011-2012 and only one single result (of 6.86 mg/L) was below the dissolved oxygen minimum objective of 7 mg/L. This particular measurement was collected from site FRA1 at the end of the dry season, during September 2011, when Franklin Creek was stagnant, cloudy, and barely trickling over the concrete ledge at the edge of JOMU property. The dissolved oxygen mean at this site was 10.030 mg/L, which was among the highest in the SFAN (Figure 13).

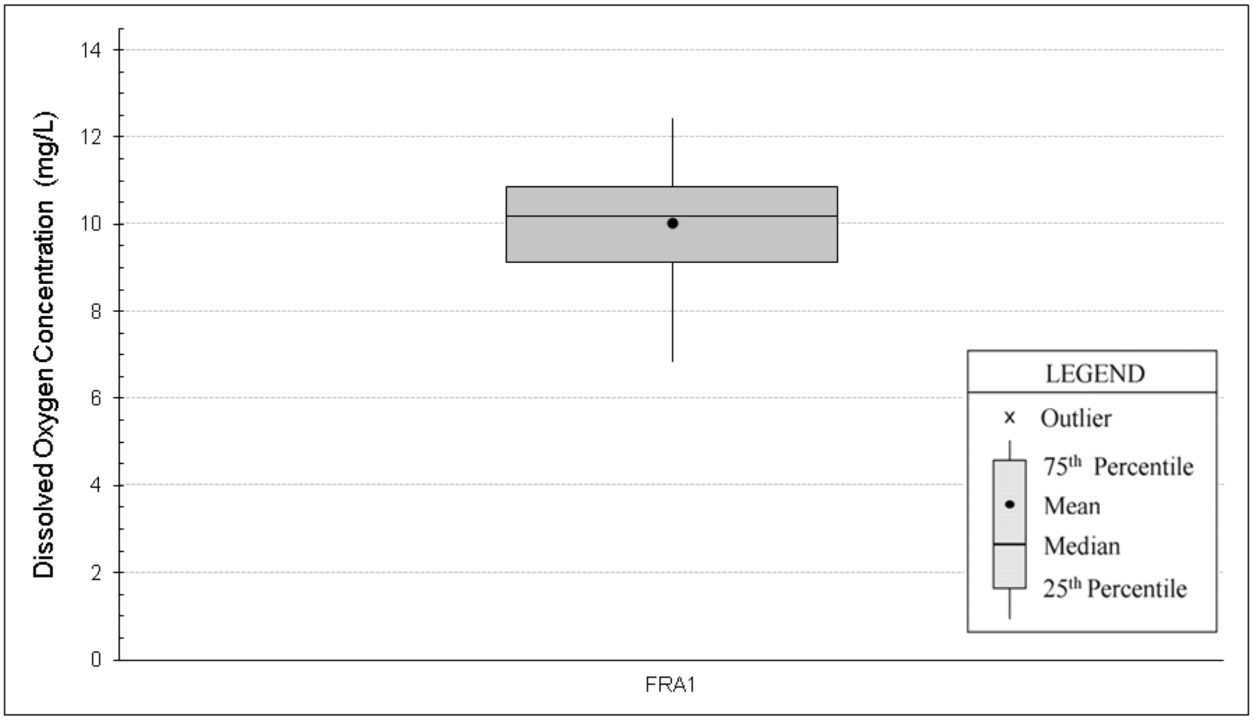

Figure 13. Dissolved oxygen results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

pH

The pH water quality objective for surface waters in PORE, GOGA, and JOMU is an optimal range of 6.5 to 8.5 pH units, based on the conditions necessary to support aquatic life (CA RWQCB 2010), while the objective range for surface waters in PINN is 7.0 to 8.5 pH units (CA RWQCB 2011). During WYs 2011-2012, 98% of all SFAN pH results fell within their objective range; only one GOGA result and 13 PINN results (out of 630 SFAN pH results) failed to meet these water quality objectives.

A total of 315 pH results were collected from the PORE sites during WYs 2011-2012, and all of these fell within the objective range of 6.5 to 8.5 pH units (Figure 14). Out of these 315 results, the highest 10% (35 of 315) were all found at site OLM6A on Davis Boucher Creek, a tributary of Olema Creek, which also produced the highest mean in PORE (8.029 pH units). OLM6A is the only Olema Creek watershed site that flows from the east side of the San Andreas Fault, and the significantly different geology could explain the higher pH values often recorded here (Cooprider 2004). All of the PINN results were above the 6.5 pH unit threshold as well; however, they must be compared to the 7.0 pH unit minimum objective instead, because PINN is within the Central Coast RWQCB. Nine percent of the PINN pH results (13 of 146) failed to meet the water quality objective range of 7.0 to 8.5 pH units; most of these (12 of 13) were below the objective range, while only one result exceeded the high end of the objective range (Figure 15). This single result (8.60 pH units at site SC1) was the only pH exceedance in the SFAN; this site also produced most of the highest results in PINN (11 of the 12 highest), as well as the highest pH mean in the SFAN (8.215 pH units).

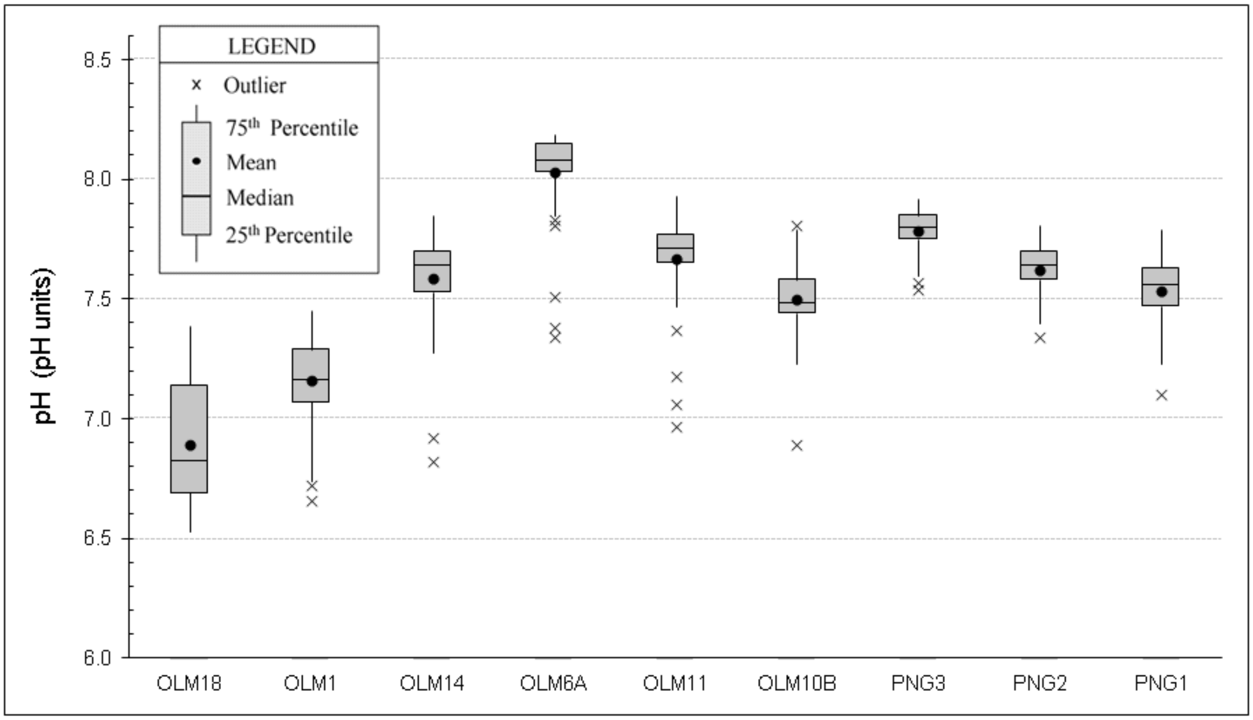

Figure 14. pH results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

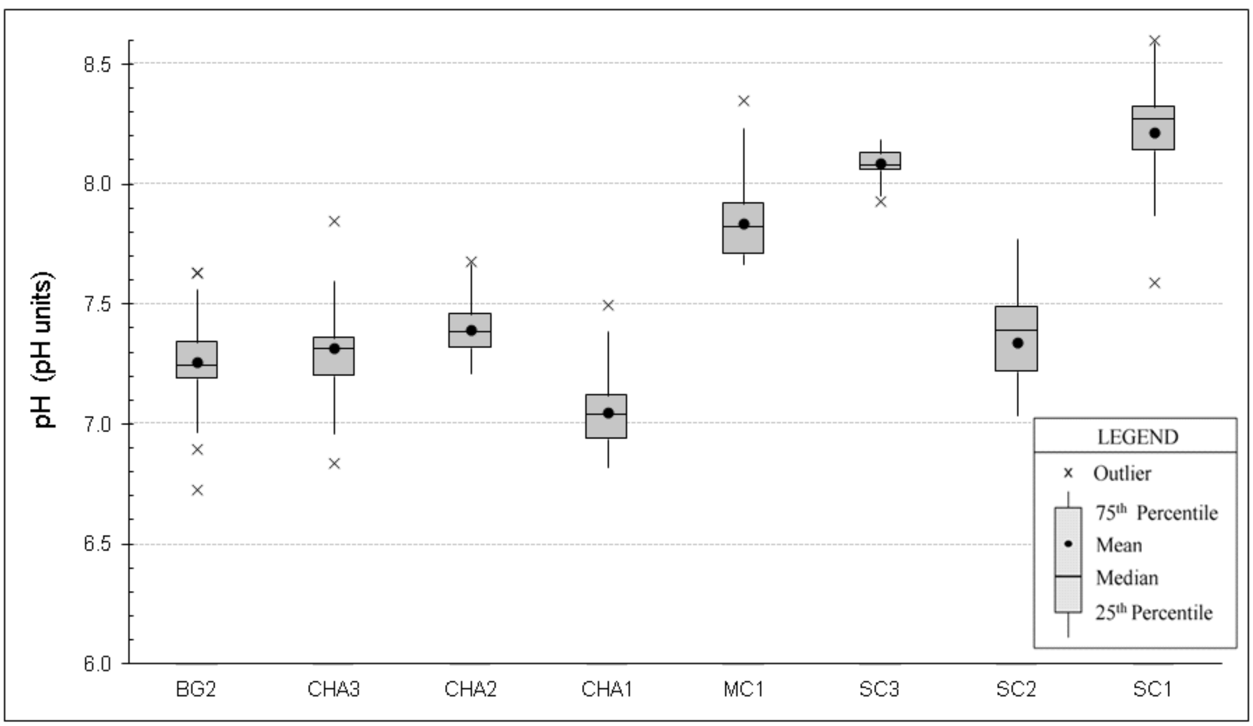

Figure 15. pH results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

One-hundred and forty-three pH readings were collected from the GOGA sites during WYs 2011-2012, and over 99% of these fell within the water quality objective range of 6.5 to 8.5 pH units (Figure 16). A single result of 6.44 pH units (collected from site OAK1) fell below the objective range on one occasion; this was also the lowest individual value recorded in the entire SFAN during the monitoring period. The lowest mean pH value (6.952 units) was calculated from site TV2 in Tennessee Valley Creek, which also produced eight of the ten lowest results in GOGA. Franklin Creek in JOMU produced the second highest pH mean in the SFAN, and some of the highest individual results. These results were consistently high, as site FRA1 had one of the narrowest ranges of pH results in the SFAN (Figure 17). No seasonal patterns were discovered during either water year of monthly monitoring in the SFAN.

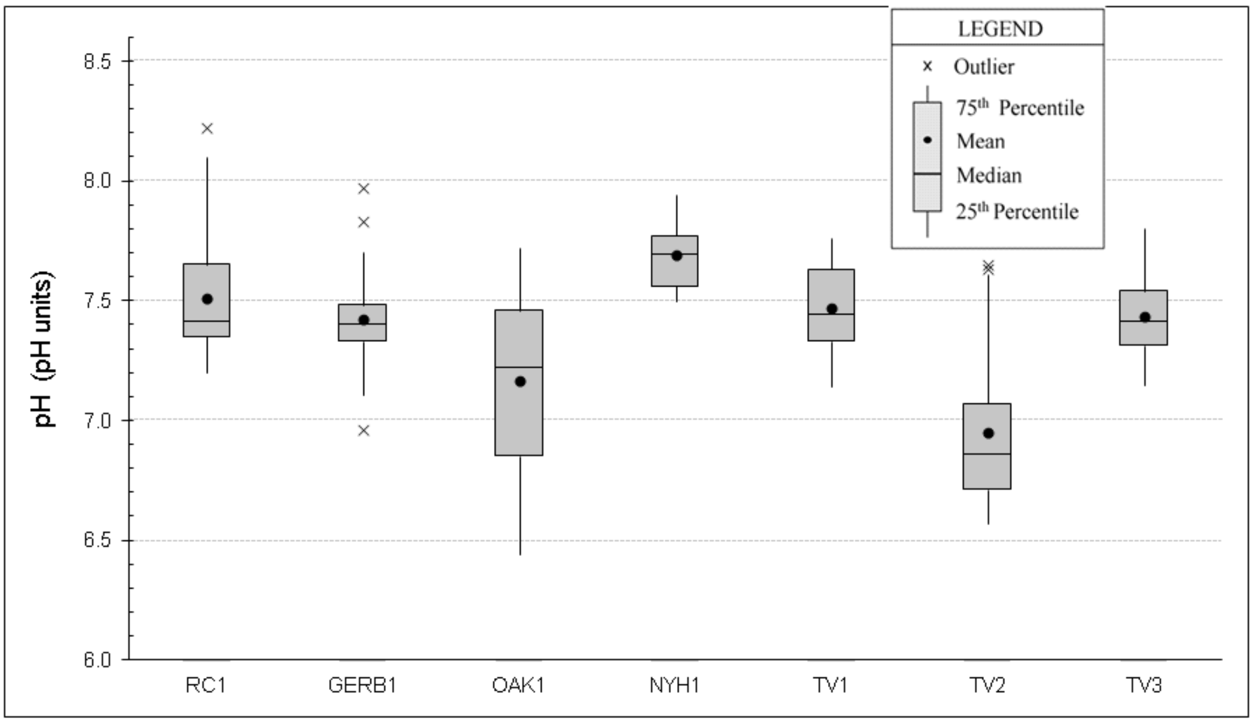

Figure 16. pH results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

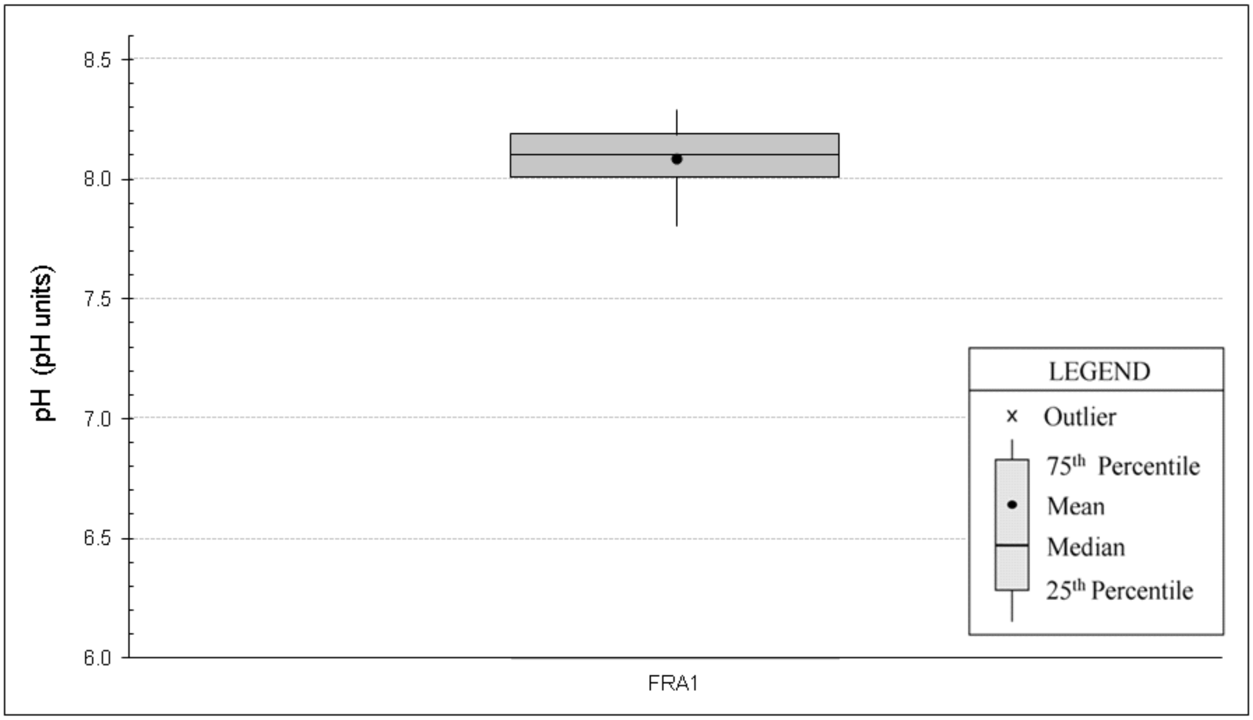

Figure 17. pH results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

Specific Conductance

Conductivity (the ability of a solution to conduct an electrical current) is an indicator of the presence of dissolved solids, and is influenced by local geology as well as urban runoff and other anthropogenic inputs. Since conductivity fluctuates with temperature, a value of "specific conductance" is calculated in-situ using the simultaneously-measured water temperature value, in order to yield a value that is corrected to 25°C. The RWQCB Basin Plans do not provide established water quality objectives for specific conductance. Ideally, freshwater streams should have specific conductance levels below 500 µS/cm in order to support diverse aquatic life; this threshold is used as an ecological objective in this report, in order to give context to the results (Behar 1997).

During WYs 2011-2012, 85% of all SFAN specific conductance results (532 of 624) fell below the ecological objective maximum of 500 µS/cm. Of those that exceeded the objective, 71% were results from PINN sites, 25% from JOMU sites, and 4% from GOGA; no exceedances were found in PORE. The highest result from the PORE dataset was a value of 418.5 µS/cm at the farthest downstream Olema Creek watershed site (OLM10B) during the first significant rainfall of WY 2011. The lowest five percent of all PORE results (14 of 294) were from the farthest upstream Olema Creek watershed sites, OLM18 and OLM1. Each PORE site exhibited fairly consistent specific conductance levels throughout each water year, and there was not much variation amongst sites (Figure 18).

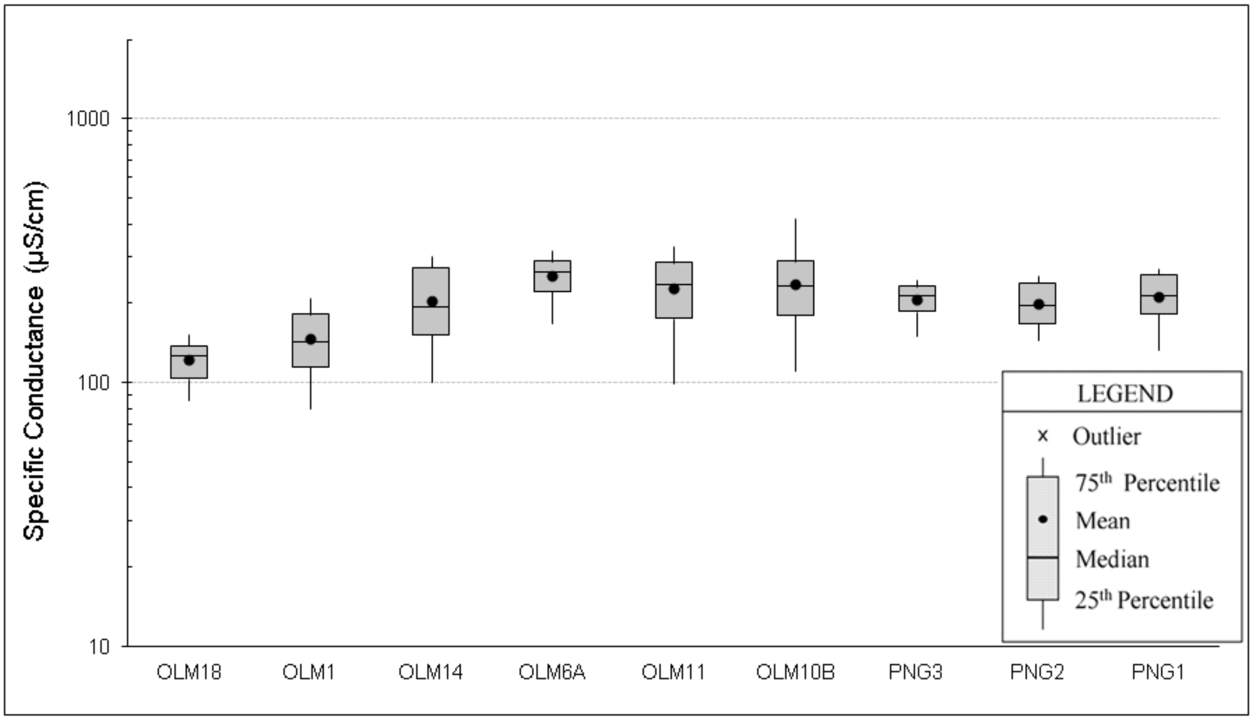

Figure 18. Specific conductance results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

During WYs 2011-2012, the majority of specific conductance exceedances (over the 500 µS/cm ecological objective maximum) were found in PINN. Forty percent of all PINN results (65 of 162) exceeded this value, and the majority of these (80%) were from the three Sandy Creek sites (SC1, SC2, and SC3); the other 20% of exceedances were all from site CHA1 in Chalone Creek (Figure 19). These four sites produced the highest means of all the PINN sites. The lowest individual specific conductance result in the SFAN was also from PINN; site BG2 in Bear Gulch measured 36.0 µS/cm after a rain event in March of 2011. In contrast to the PINN dataset, the GOGA results only had a three percent exceedance rate. Just four GOGA results (two each from TV2 and NYH1) out of 143 exceeded 500 µS/cm. These two sites, TV2 and NYH1, also produced the widest ranges in specific conductance values compared to all other GOGA sites (Figure 20). Site TV1 in GOGA produced the lowest mean specific conductance value in the SFAN (113.20 µS/cm), while site FRA1 in JOMU produced the highest mean (1214.00 µS/cm) (Figure 21). FRA1, in Franklin Creek, also produced the highest individual specific conductance result in the SFAN (1514.0 µS/cm). Ninety-two percent of all JOMU results (23 of 25) exceeded the ecological objective maximum of 500 µS/cm; the only two samples that fell below this level were collected from Strentzel Creek during a March 2012 storm sampling event.

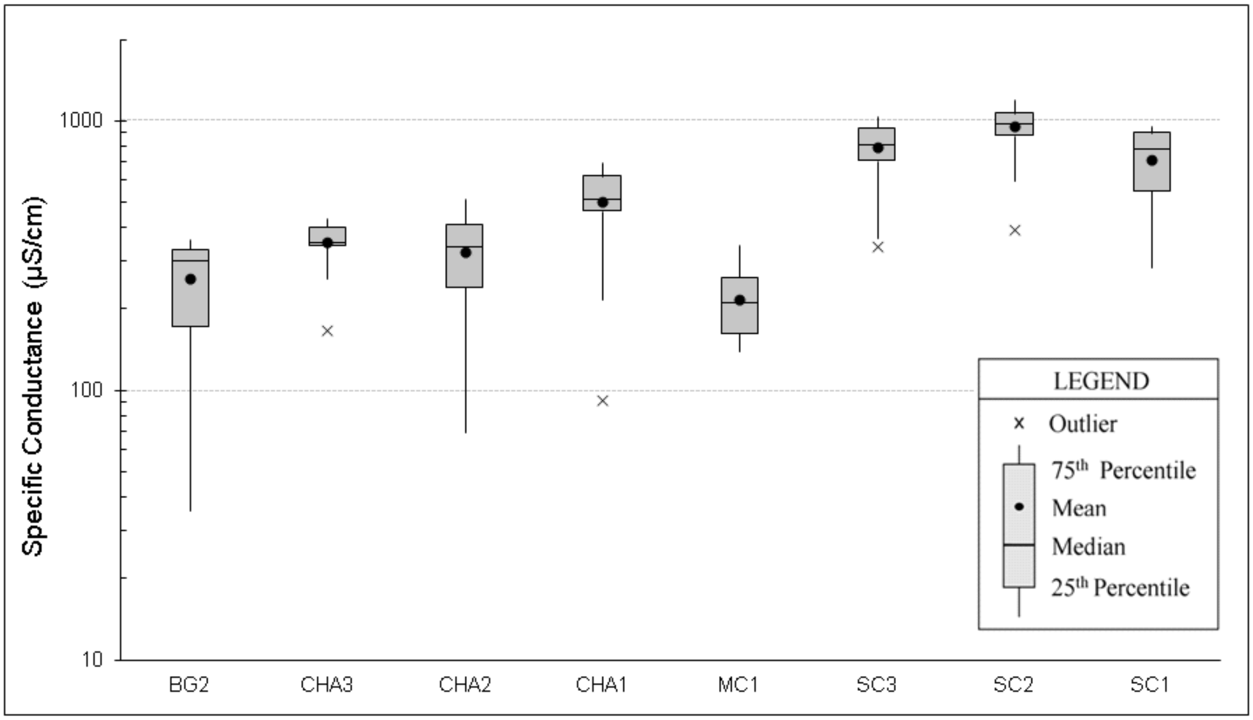

Figure 19. Specific conductance results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

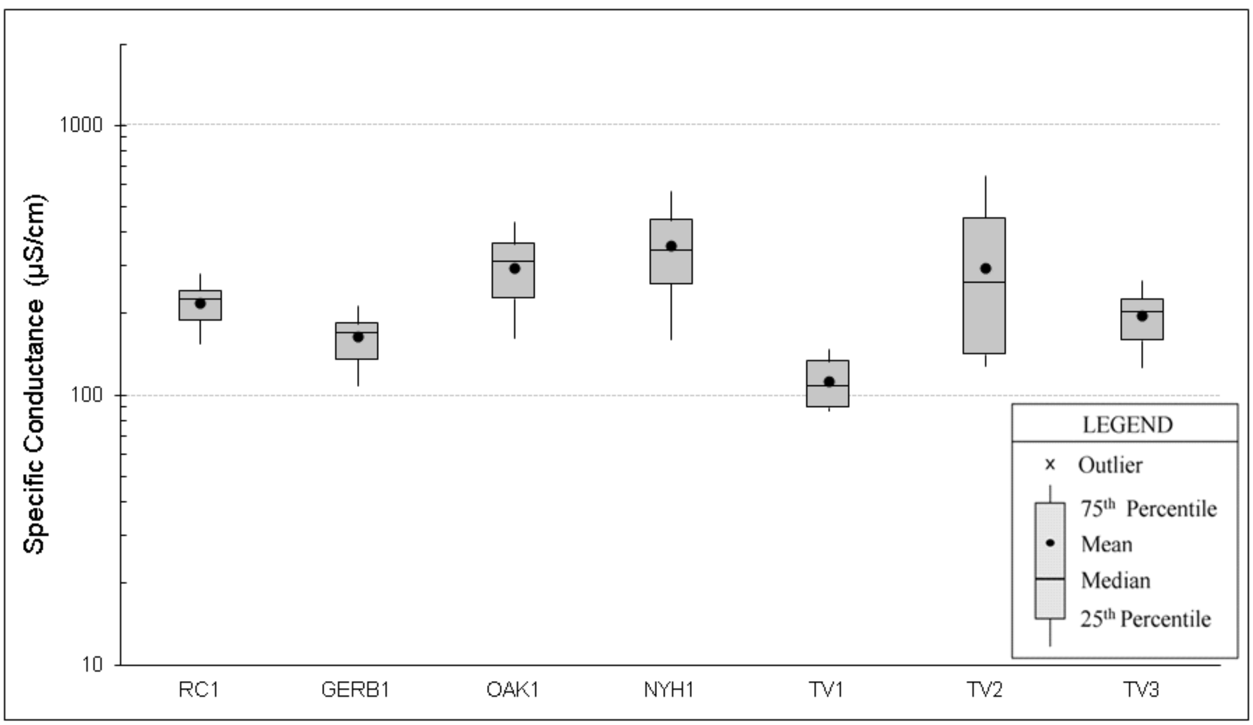

Figure 20. Specific conductance results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

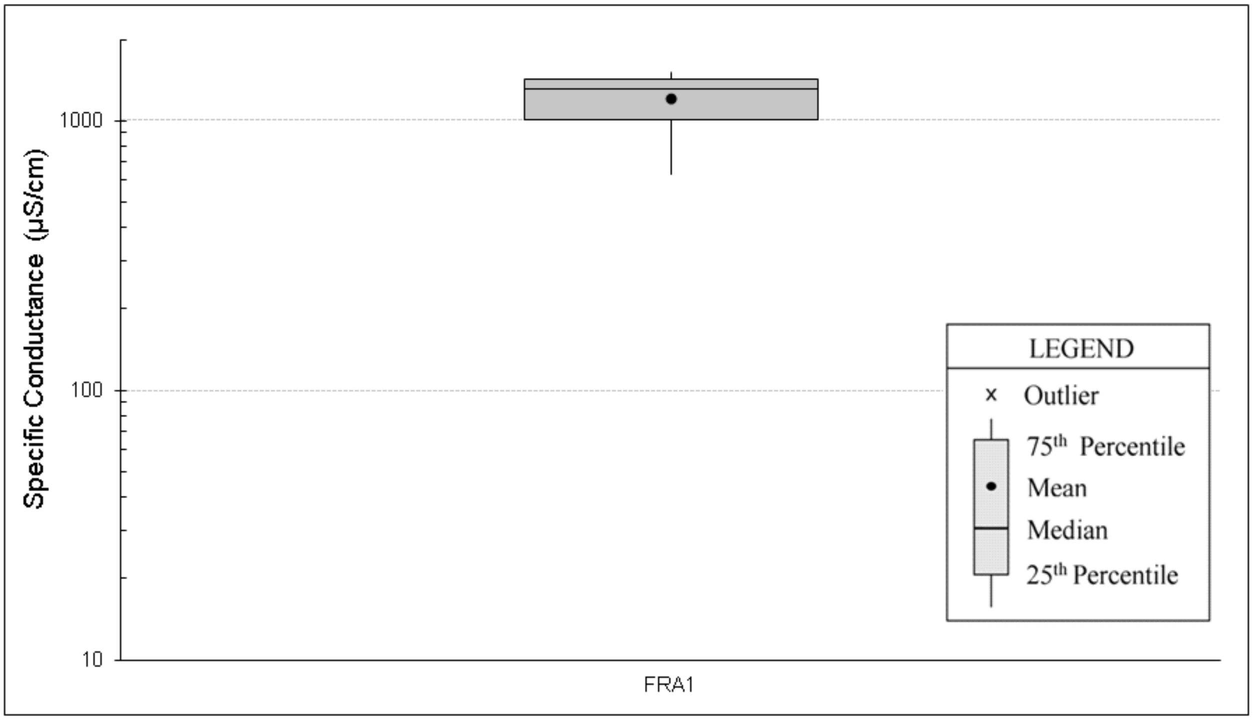

Figure 21. Specific conductance results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

Turbidity

Turbidity is the capacity of suspended sediment (including clay, silt, fine organic and inorganic matter, and microscopic organisms) in water to scatter light (American Public Health Association et al. 1998). Inputs of such solids occur because of erosion from stream banks, runoff from various source areas within a watershed, and re-suspension from the streambed during storm events. While erosion and sedimentation are natural processes, agriculture and land development can accelerate these means of sediment transport and result in an imbalance in the amount of sediment in a stream system (Cooprider and Carson 2006). Turbidity is often measured in nephelometric turbidity units (NTU). A level of turbidity greater than 5 NTU is considered visible turbidity, and turbidity levels above 25 NTU have been shown to cause reductions in salmonid growth (Sigler et al. 1984). There is not an established objective for turbidity levels in SFAN streams, but the ecological objective maximum of 25 NTU is kept in mind when looking at these results. Additionally, the NPS Water Resource Division uses a “screening criteria” of 50 NTU to determine water quality exceedances in its Baseline Water Quality Inventory and Analysis Reports (NPS 2003). Although these objectives are important to keep in mind, it is often not the peak levels that determine negative ecological consequences, but the persistence of high levels after storm events; longer durations of high turbidity levels are more likely to cause damage to fish and other aquatic organisms (Newcombe and MacDonald 1991). This program captures single turbidity samples during site visits, and does not conduct continuous monitoring or turbidity threshold sampling.

During WYs 2011-2012, a total of 664 turbidity samples were collected from SFAN streams; 14% of these exceeded the ecological objective maximum of 25 NTU, and exceedances were found in every park unit. The PORE sites produced some of the highest individual results during storm events, yet PORE had the lowest overall rate of exceedance amongst the four parks (7% of turbidity samples exceeded 25 NTU). Every exceedance in PORE (22 out of 318) was found in the Olema Creek watershed; this is part of the Lagunitas Creek watershed, which the San Francisco Bay RWQCB has identified as "impaired" by sediment. The 19 highest results were collected during rain events. All turbidity results from the Pine Gulch watershed sites in PORE fell below the ecological objective maximum of 25 NTU; these sites produced three of the five lowest means in the SFAN (Figure 22).

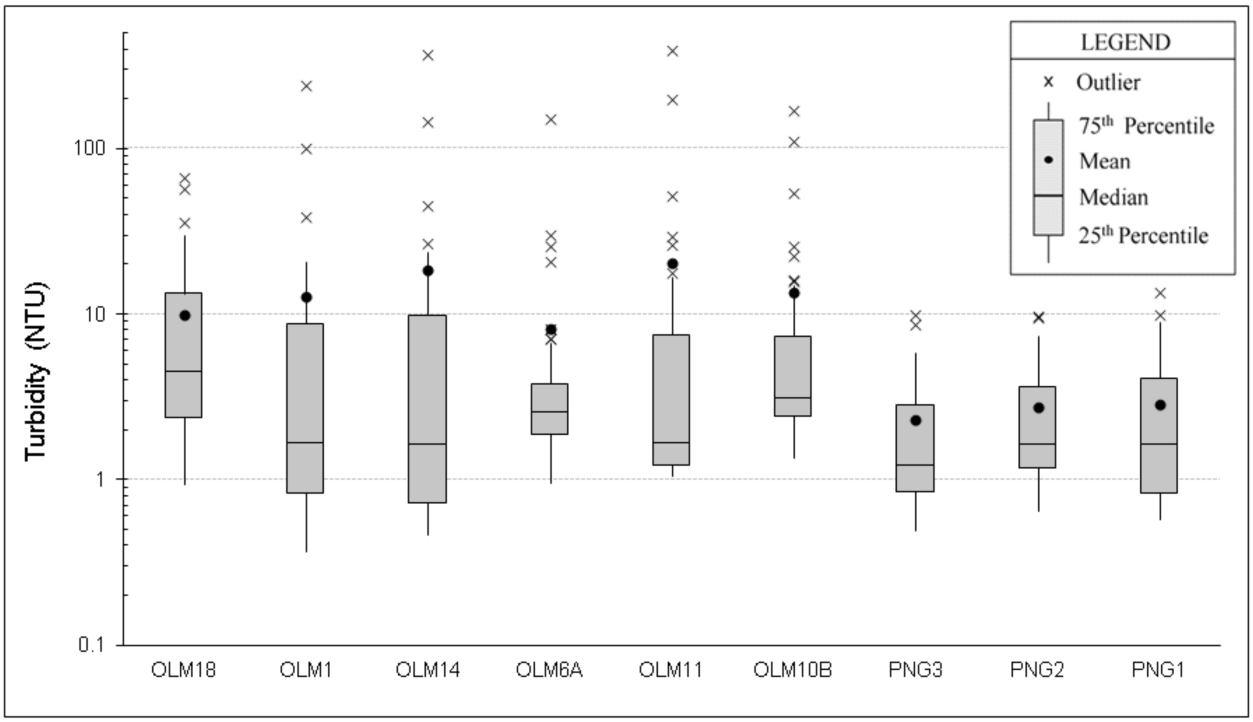

Figure 22. Turbidity results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

The results from the PINN sites were highly varied during WYs 2011-2012; the highest mean turbidity (for a single site) was found here, as well as the two lowest means in the SFAN. Twenty-one percent of the PINN results (35 of 169) exceeded the ecological objective maximum of 25 NTU, and the majority of these (25 of 35) were from site MC1 in McCabe Canyon. Although many SFAN sites had high turbidity spikes, MC1 had the most consistently high turbidity values compared to all program sites; the mean was 83.5 NTU, higher than any other in the SFAN, and it also exhibited the narrowest range in results (Figure 23). All 25 turbidity results from site MC1 were above the ecological objective maximum of 25 NTU, and the lowest value recorded was 55.4 NTU. Site SC1 in Sandy Creek also produced a relatively high mean (27.91 NTU), while sites SC3 and CHA2 produced the lowest means in the SFAN (2.070 and 1.48 NTU, respectively).

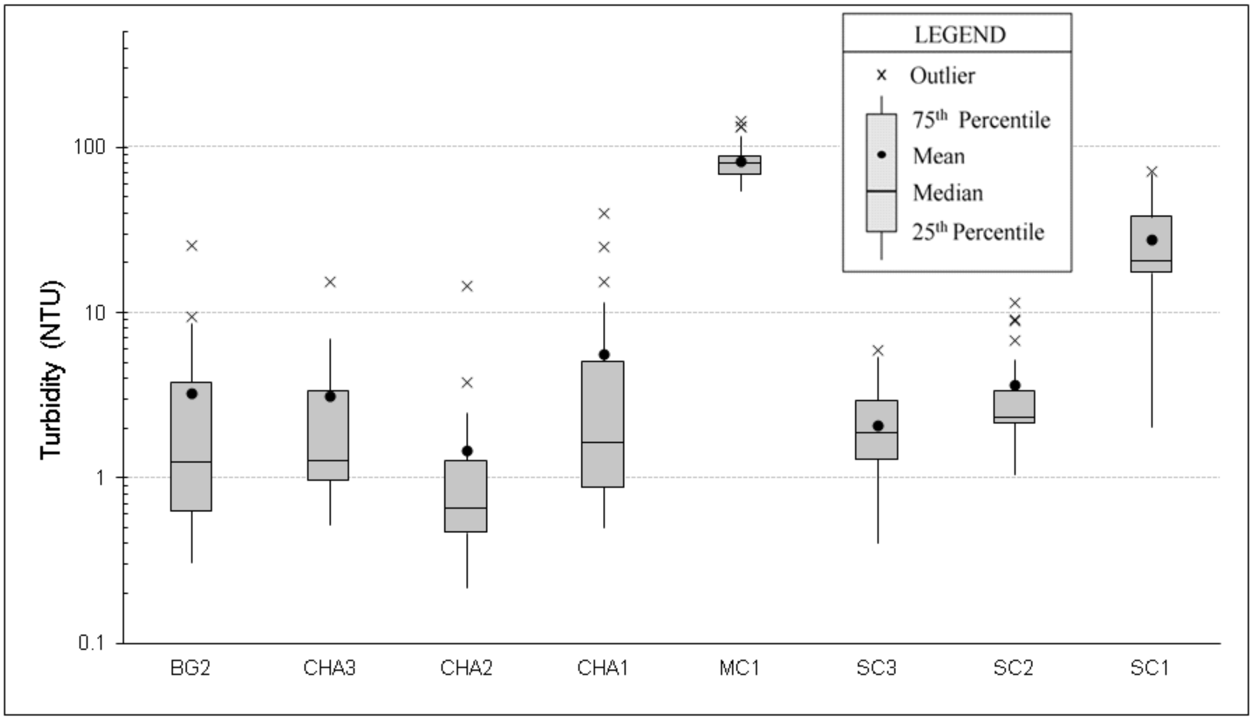

Figure 23. Turbidity results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

During WYs 2011-2012, a total of 150 turbidity samples were collected from the GOGA sites; 17% of these exceeded the ecological objective maximum of 25 NTU, and at least one exceedance was recorded at each of the seven sites. The lowest 21% of all GOGA turbidity results (32 of 150) were produced from two sites (OAK1 and NYH1); these sites also exhibited the two lowest mean turbidity values in GOGA (Figure 24). Site TV2 produced the highest individual result in the entire SFAN program (a result of 493 NTU during November 2011), as well as the highest mean value (56.4 NTU). The second highest turbidity mean in the SFAN was a value of 20.5 NTU, from site FRA1 in JOMU (Figure 25). Thirty-one percent of JOMU results (8 of 26) exceeded the ecological objective maximum of 25 NTU, and all of these exceedances were captured during storm sampling events.

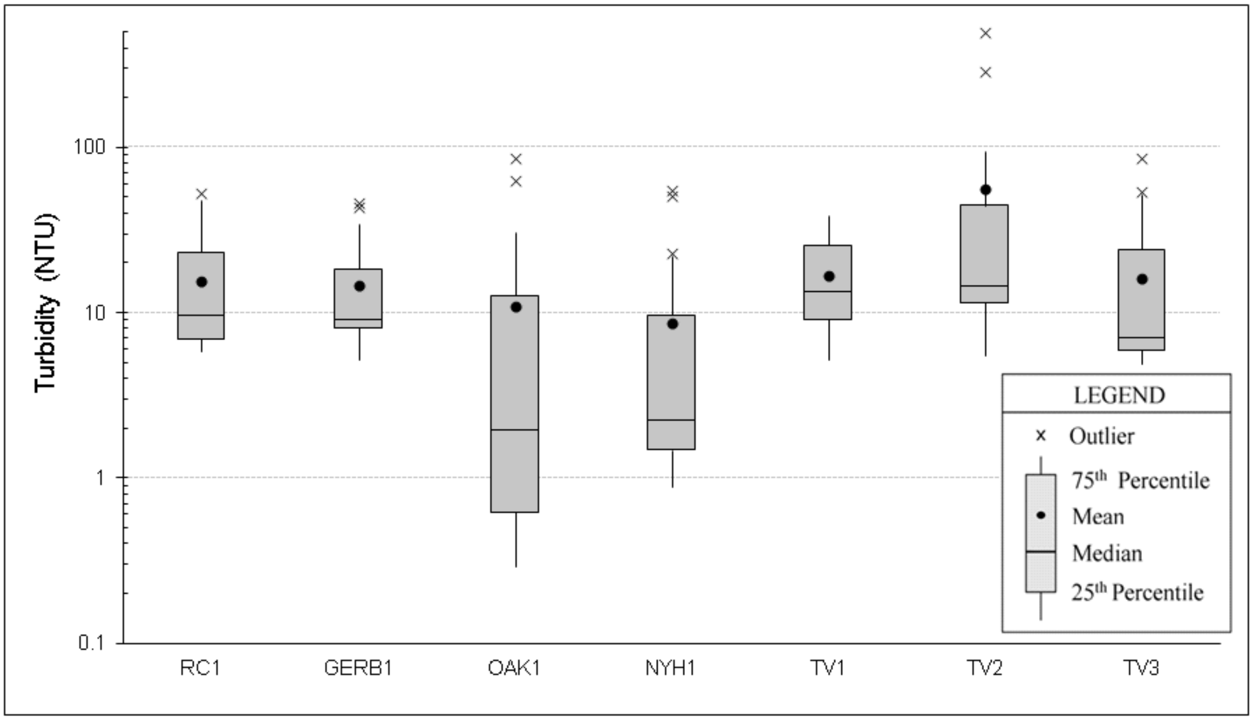

Figure 24. Turbidity results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

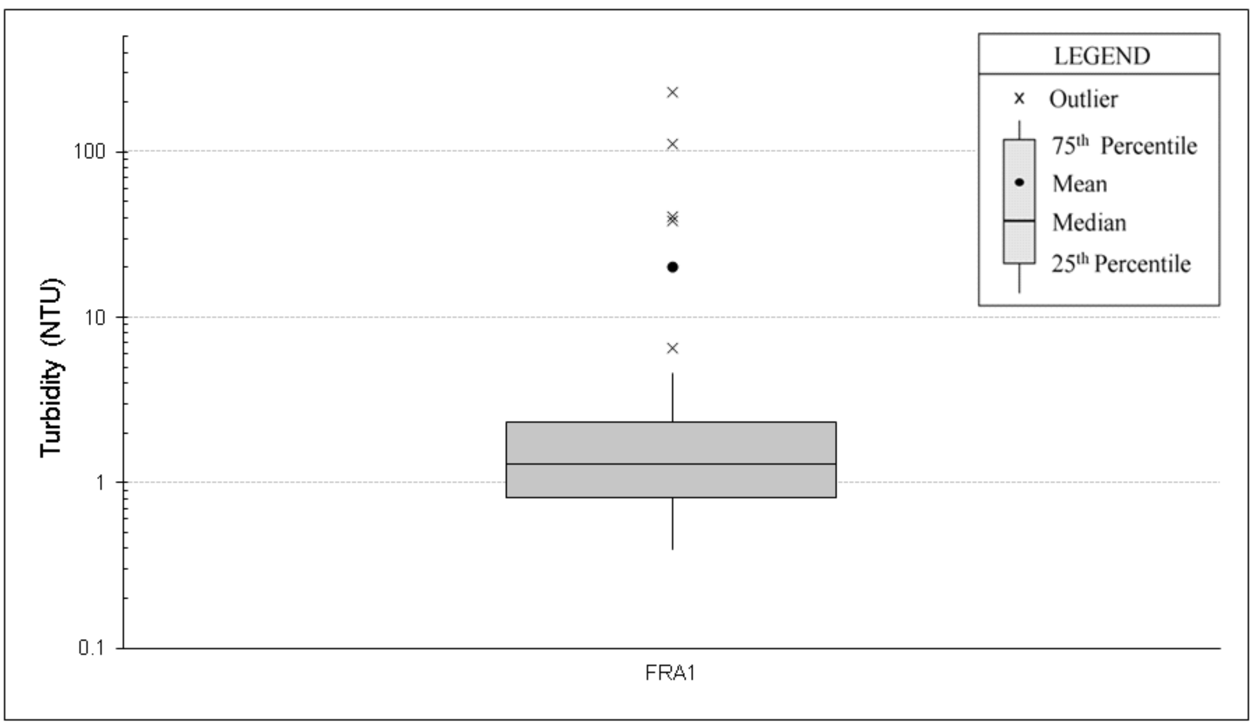

Figure 25. Turbidity results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

Nutrient Parameters

All nutrient samples were collected in sterile, laboratory-issued bottles during each site visit, and stored immediately on ice until transferred to the contracted laboratory for processing. During WYs 2011-2012, nitrate (as N) and TKN were sampled on a monthly basis (and during storms) at 20 primary SFAN water quality sites. Out of the 30 SFAN sites monitored during WYs 2011-2012, 10 were established as secondary sites in the SFAN Protocol, which excludes collection of nutrient samples. Nutrient sampling did not take place at CHA3, SC3, or SC2 (in PINN), OAK1 or TV1 (in GOGA), or at the five Strentzel Creek watershed sites (in JOMU).

Summary statistics of all nutrient data collected during WYs 2011-2012 are displayed in detail in Tables 17, 18, 19, and 20; however, box and whiskers plots of these data are displayed separately (sorted by parameter) for simplified viewing. Sites with fewer than four results are included in the summary tables, but are excluded from the figures since their datasets are too small for analysis (U.S. EPA 1998). Due to relatively low nutrient levels in the SFAN streams, many results were reported as non-detect, which means that the analyte was not detected at or above the laboratory's reporting detection limit (RDL). These results were considered censored and required the use of the nonparametric Kaplan-Meier method (through the NPSTORET database) for analysis of all SFAN nutrient results (see Data Handling and Analysis in the Methods section for a description). All summary statistics are based on instantaneous measurements routinely collected at approximately the same time of day on each visit; therefore, the data in the tables and figures presented do not reflect the true minimum and maximum values of diel variation.

Table 17. Nutrient results from Point Reyes National Seashore (water years 2011-2012). (Std. dev. = standard deviation.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	OLM18	OLM1	OLM14	OLM6A	OLM11	OLM10B	PNG3	PNG2	PNG1
Nitrate as nitrogen (mg/L)	Mean	-	0.196	0.215	0.35	0.261	0.215	0.337	0.230	0.261
	Median	-	-	0.19	0.26	0.17	-	0.30	0.23	0.21
	Minimum	<0.15	<0.15	<0.15	<0.15	<0.15	<0.15	0.19	<0.15	<0.15
	Maximum	0.27	0.78	0.64	2.0	0.93	0.95	0.57	0.42	0.67
	Std. dev.	-	0.130	0.100	0.37	0.188	0.171	0.103	0.069	0.122
	# NDs/ # Results[1]	22/24	15/24	4/24	1/24	10/24	16/24	0/23	4/23	2/23
Total Kjeldahl nitrogen (mg/L)	Mean	0.38	0.306	0.38	0.37	0.41	0.47	0.355	0.336	0.406
	Median	0.35	0.27	0.33	0.32	0.36	0.42	0.33	0.30	0.35
	Minimum	0.25	<0.25	0.25	<0.25	<0.25	0.31	<0.25	<0.25	<0.25
	Maximum	1.0	0.89	1.2	1.0	1.5	1.4	0.73	0.57	0.82
	Std. dev.	0.14	0.130	0.19	0.18	0.25	0.21	0.121	0.094	0.157
	# NDs/ # Results[1]	0/24	8/24	0/24	2/24	1/24	0/24	5/23	2/23	3/23

[1] The number of results that were reported as 'ND' (not detected at or above the reporting detection limit) are shown above, as a ratio over the total number of results from that site.
- Dashes are inserted where a high percentage of censoring prevents calculation.

Table 18. Nutrient results from Pinnacles National Park (water years 2011-2012). (Std. dev. = standard deviation.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	BG2	CHA2	CHA1	MC1	SC1
Nitrate as nitrogen (mg/L)	Mean	-	-	-	0.249	-
	Median	-	-	-	-	-
	Minimum	<0.15	<0.15	<0.15	<0.15	<0.15
	Maximum	0.39	<0.15	0.23	0.83	0.19
	Std. dev.	-	-	-	0.195	-
	# NDs/ # Results[1]	19/24	24/24	22/24	12/24	17/18
Total Kjeldahl nitrogen (mg/L)	Mean	0.48	0.44	0.44	1.65	0.83
	Median	0.46	0.41	0.44	1.5	0.75
	Minimum	0.25	0.27	0.25	0.82	0.53
	Maximum	1.0	1.1	1.0	4.1	1.5
	Std. dev.	0.17	0.17	0.15	0.80	0.26
	# NDs/ # Results[1]	0/24	0/24	0/24	0/24	0/18

[1] The number of results that were reported as 'ND' (not detected at or above the reporting detection limit) are shown above, as a ratio over the total number of results from that site.
- Dashes are inserted where a high percentage of censoring prevents calculation.

Table 19. Nutrient results from Golden Gate National Recreation Area (water years 2011-2012). (Std. dev. = standard deviation.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	RC1	GERB1	NYH1	TV2	TV3
Nitrate as nitrogen (mg/L)	Mean	-	-	-	-	-
	Median	-	-	-	-	-
	Minimum	<0.15	<0.15	<0.15	<0.15	<0.15
	Maximum	<0.15	0.19	<0.15	0.22	0.23
	Std. dev.	-	-	-	-	-
	# NDs/ # Results[1]	23/23	21/23	23/23	18/20	21/23
Total Kjeldahl nitrogen (mg/L)	Mean	0.529	0.49	0.448	0.90	0.54
	Median	0.51	0.45	0.40	0.59	0.48
	Minimum	0.36	0.33	<0.25	0.32	0.35
	Maximum	0.94	1.0	0.87	5.6	1.1
	Std. dev.	0.152	0.17	0.163	1.13	0.21
	# NDs/ # Results[1]	0/23	0/23	1/23	0/20	0/23

[1] The number of results that were reported as 'ND' (not detected at or above the reporting detection limit) are shown above, as a ratio over the total number of results from that site.
- Dashes are inserted where a high percentage of censoring prevents calculation.

Table 20. Nutrient results from John Muir National Historic Site (water years 2011-2012). (Std. dev. = standard deviation.) All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	FRA1
Nitrate as nitrogen (mg/L)	Mean	1.27
	Median	1.20
	Minimum	0.50
	Maximum	3.3
	Std. dev.	0.57
	# NDs/ # Results[1]	0/22
Total Kjeldahl nitrogen (mg/L)	Mean	0.56
	Median	0.40
	Minimum	0.28
	Maximum	1.7
	Std. dev.	0.37
	# NDs/ # Results[1]	0/22

[1] The number of results that were reported as 'ND' (not detected at or above the reporting detection limit) are shown above, as a ratio over the total number of results from that site.

Nitrate as N (Nitrogen)

Neither the State of California nor the San Francisco Bay RWQCB has set objectives for nitrates, however, there is a national drinking water objective of 10 mg/L nitrate (as N) established by the EPA, as well as a regional reference value of 0.16 mg/L (U.S. EPA 2000). Additionally, R. Crunkilton (2000) found that a level of 1.1 mg/L nitrate (as N) can be toxic to aquatic life, especially fish and amphibian eggs. For this report, SFAN nitrate results are compared to the ecological threshold of 1.1 mg/L nitrate (as N) (Crunkilton 2000). The RDL for all nitrate (as N) samples processed during WYs 2011-2012, was 0.15 mg/L (utilizing EPA Method 300).

A total of 462 nitrate (as N) samples were collected from the 20 SFAN primary sites during WYs 2011-2012. Ninety-seven percent of these were determined to be below the ecological objective maximum of 1.1 mg/L; only 13 individual samples (out of 462) exceeded this objective, and almost all of these (12 of 13) were from Franklin Creek in JOMU, the most urbanized creek monitored by this program. Every water quality sample collected in PINN and GOGA registered below the ecological objective maximum for nitrate (as N), and most of these had undetectable levels; 83% of PINN samples (95 of 115), and 95% of GOGA samples (106 of 112) were reported as non-detect. Because of these high percentages of censored data, figures can not be created for these park units.

During WYs 2011-2012, every PORE site produced at least two nitrate (as N) results above the RDL of 0.15 mg/L. OLM18 (the most upstream site in the Olema Creek watershed) produced the lowest nitrate (as N) results in PORE; 92% of samples from this site (22 of 24) were reported as non-detect, and the highest recorded result was 0.27 mg/L, well below the ecological objective maximum of 1.1 mg/L. Of all PORE sites, OLM6A produced the highest mean nitrate (as N) value (0.35 mg/L), as well as the highest individual result. This single value of 2.0 mg/L was collected during a storm sampling event in January 2012, and was the only result from PORE (out of 213 samples) that exceeded the ecological objective maximum (Figure 26). PNG3 was the only PORE site that had detectable nitrate (as N) levels on every water quality sampling day. This site did not produce any exceedances, but it had the highest mean in the Pine Gulch watershed (0.337 mg/L), very close to that of site OLM6A. Except for the single exceedance from site OLM6A, all SFAN exceedances were found at site FRA1 in JOMU. During WYs 2011-2012, a total of 22 samples were collected from FRA1, and every one of them had detectable levels of nitrate (as N) above the RDL of 0.15 mg/L. These results ranged from 0.50 to 3.3 mg/L (Figure 27). This site produced 13 of the 14 highest results in the SFAN (12 of which exceeded the ecological objective), as well as the highest mean (1.27 mg/L) and highest individual result (3.3 mg/L) in the SFAN program.

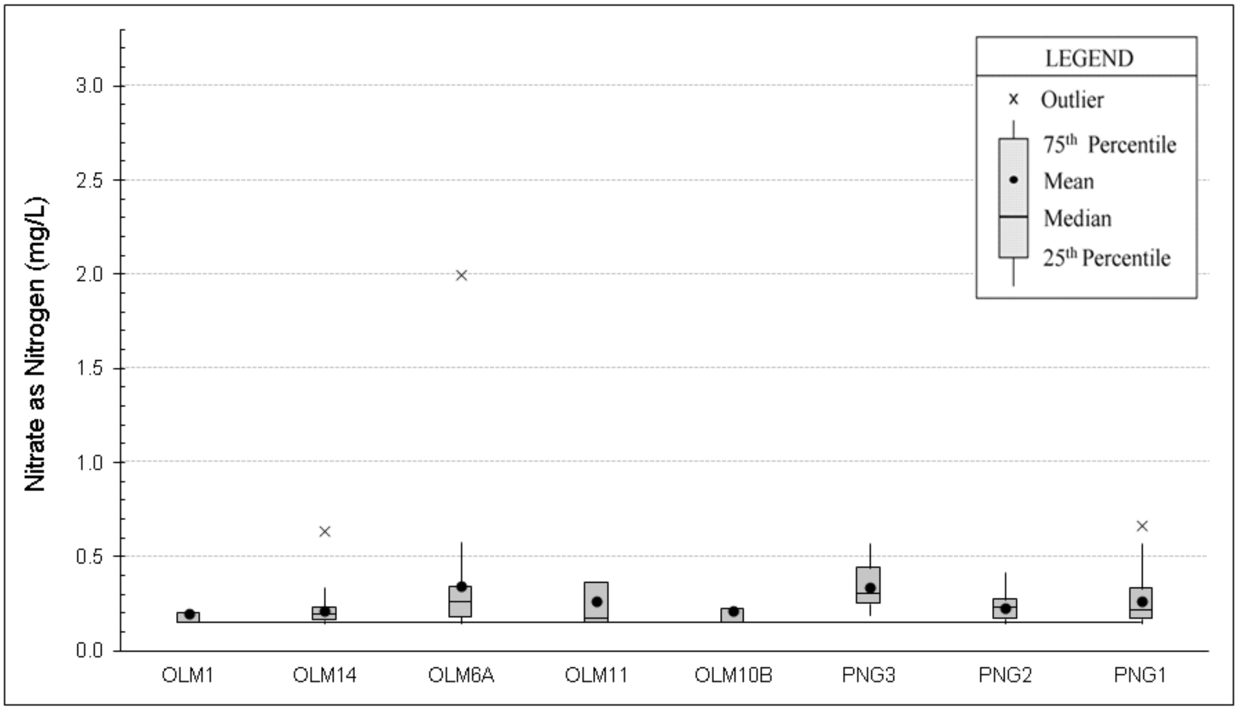

Figure 26. Nitrate (as nitrogen) results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for sites OLM1, OLM11, and OLM10B (high censoring prevented computation). OLM18 was excluded due to its high percentage of censored data. The laboratory reporting detection limit (0.15 mg/L) is displayed with a solid line.

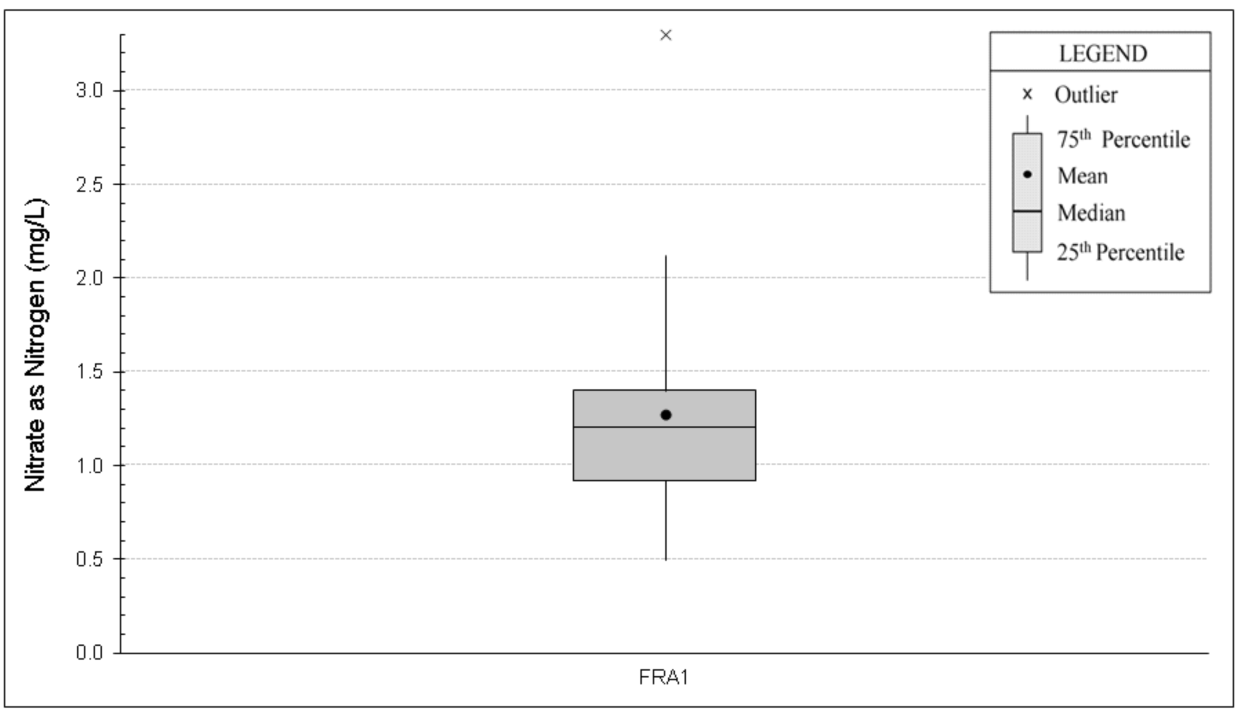

Figure 27. Nitrate (as nitrogen) results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

Total Kjeldahl Nitrogen (TKN)

Combined ammonia-nitrogen and organic nitrogen are referred to as TKN. Different forms of nitrogen can exist in streams as a result of both natural and anthropogenic sources. Monitoring TKN, in addition to nitrate and ammonia, can create a clearer understanding of what forms of nitrogen (organic or inorganic) are available at different times of the year. The San Francisco Bay RWQCB's Basin Plan does not currently have an established criterion for TKN; however, the EPA encouraged the establishment of regulatory objectives for nutrients by conducting a large scale survey to provide states with regional reference values. The regional reference value for SFAN streams is 0.36 mg/L TKN (U.S. EPA 2000).

During WYs 2011-2012, the laboratory's RDL for all TKN tests (Standard Method 4500-Norg C) was 0.25 mg/L, and 95% of all SFAN samples (440 of 462) were reported to be above this level. The eight lowest mean TKN values, and nearly all the non-detect results (21 of 22) in the SFAN were from PORE monitoring sites. Forty-three percent of the PORE results exceeded the regional reference value of 0.36 mg/L; the highest mean (of these nine sites) was a value of 0.47 mg/L, produced by the farthest downstream Olema Creek site (OLM10B) (Figure 28). The highest individual results in PORE were captured during storm sampling events.

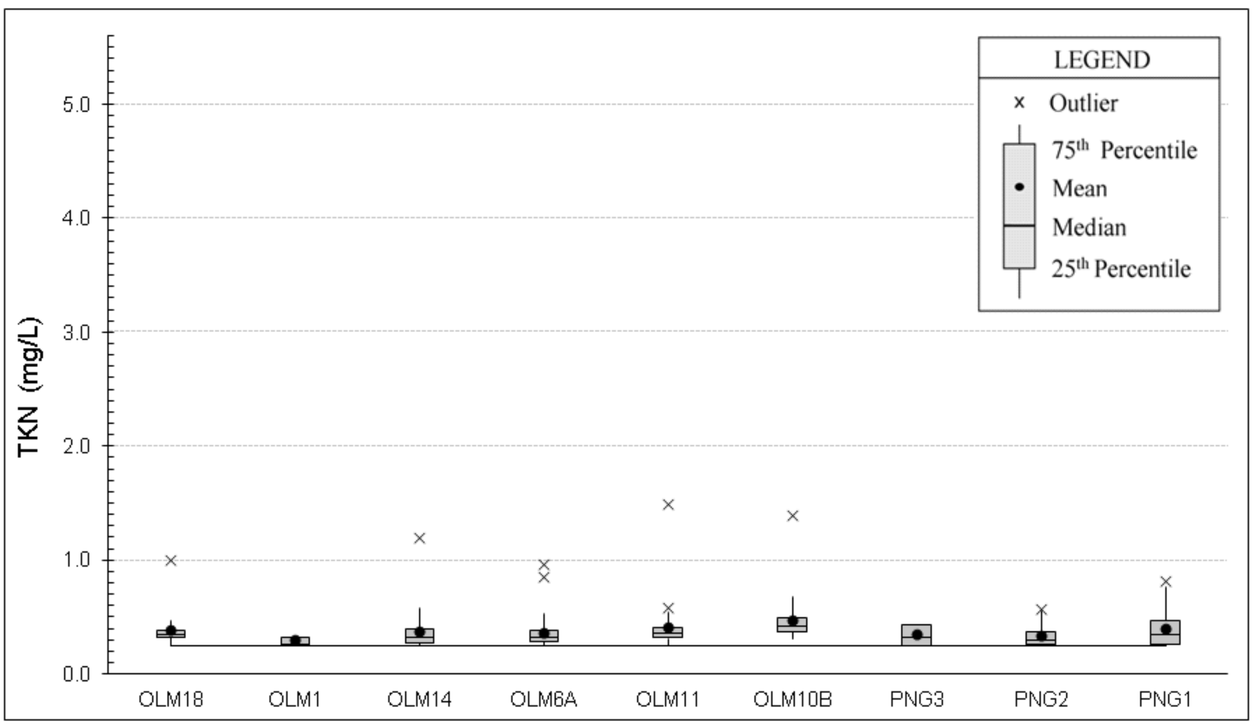

Figure 28. Total Kjeldahl nitrogen (TKN) results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for sites OLM1 and PNG3 (high censoring prevented computation). The laboratory reporting detection limit (0.25 mg/L) is displayed with a solid line.

All samples collected from PINN during WYs 2011-2012 had detectable levels of TKN, and 81% of these results (93 of 115) were above the regional reference value of 0.36 mg/L. Site MC1, in McCabe Canyon, produced the highest TKN mean in the SFAN and the second highest individual result in the program (4.1 mg/L in July 2012) (Figure 29). Seven out of the eight highest MC1 results were recorded during low flows in the dry season.

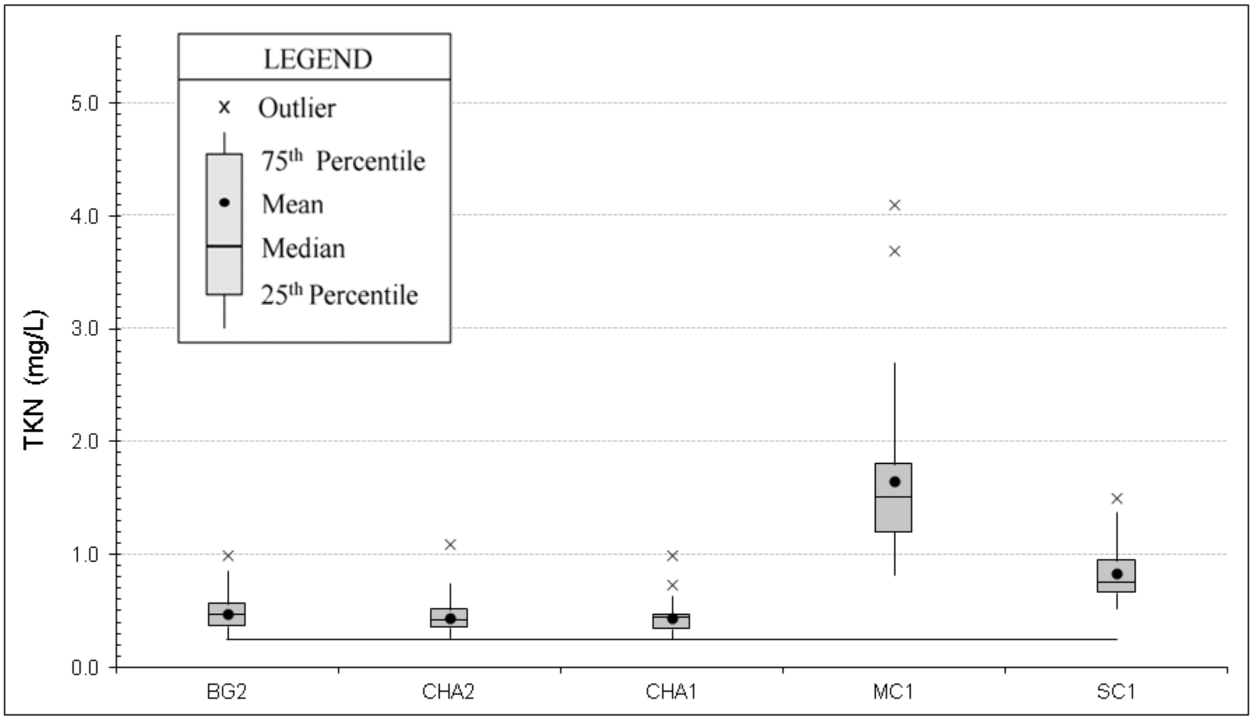

Figure 29. Total Kjeldahl nitrogen (TKN) results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range. The laboratory reporting detection limit (0.25 mg/L) is displayed with a solid line.

During WYs 2011-2012, 87% of all GOGA TKN results (97 of 112) exceeded the regional reference value of 0.36 mg/L. Only one of the GOGA samples had undetectable levels of TKN (below the RDL of 0.25 mg/L); this single non-detect value was collected from site NYH1 during low flow conditions in May 2012. This site, in Nyhan Creek, produced the lowest mean TKN value of all GOGA sites (0.448 mg/L). Site TV2 in Tennessee Valley Creek produced the highest mean of all GOGA sites (0.90 mg/L) as well as the highest individual result program-wide (Figure 30); Figure 31 shows the surface water conditions of this single high result (5.6 mg/L), collected during the November 2011 sampling in low flow conditions.

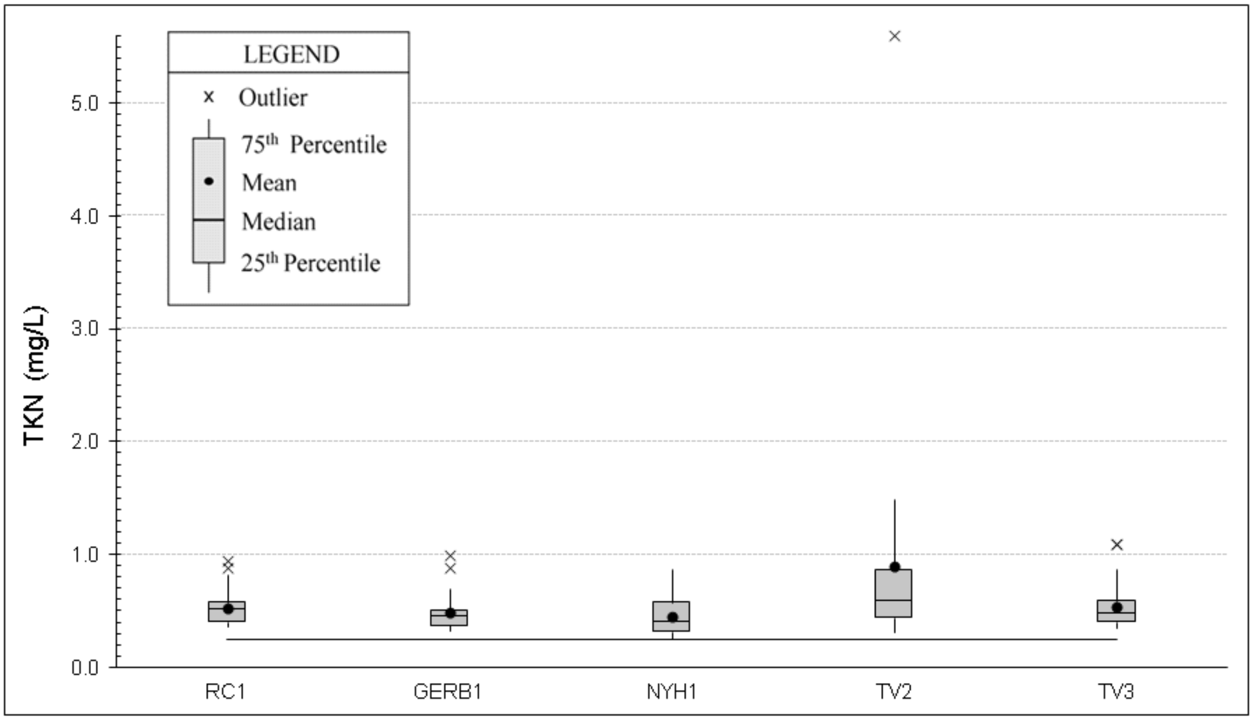

Figure 30. Total Kjeldahl nitrogen (TKN) results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range. The laboratory reporting detection limit (0.25 mg/L) is displayed with a solid line.

Figure 31. Surface of water at site TV2 in Tennessee Valley Creek. This photograph was taken during the same site visit that produced the highest TKN result in the SFAN Program during WYs 2011-2012.

During WYs 2011-2012, a total of 22 nutrient samples were collected from site FRA1 in JOMU and all had detectable levels of TKN above the laboratory RDL of 0.25 mg/L. Sixty-eight percent of these samples (15 of 22) exceeded the regional reference value of 0.36 mg/L (Figure 32). The four highest TKN values were captured during rain events.

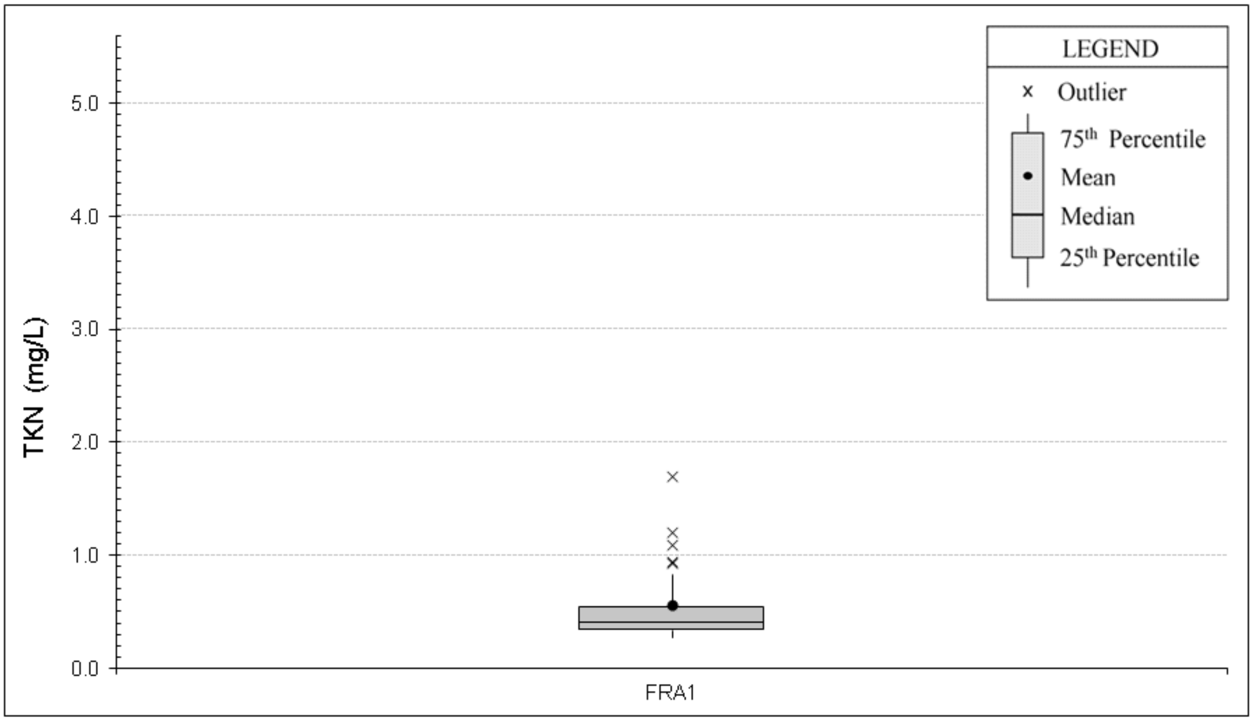

Figure 32. Total Kjeldahl nitrogen (TKN) results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range. All FRA1 results were above the laboratory reporting detection limit of 0.25 mg/L.

Pathogenic Indicator Bacteria

Total coliform, *Escherichia coli (E. coli)*, and fecal coliform bacteria are indicators of pathogens that can be detrimental to human health. The results from these parameters are reported with the units "MPN/100mL" which stands for "most probable number of colony-forming units per 100 mL of sample volume." These results do not quantify the amount of bacteria in a body of water, but are used to estimate concentrations of bacteria that may indicate the presence of pathogens. Currently the EPA uses *E. coli* as an indicator of risk to human health, and it is the recommended parameter for fresh water. Total coliform bacteria results are automatically reported along with *E. coli*, and although these results may be used to view long-term trends in the future, total coliform is not commonly used as a pathogenic indicator for human health concerns. Since human contact with surface water is uncommon at the SFAN monitoring sites, the established objectives may seem irrelevant. However, the water from these sites may influence a variety of recreational sites downstream, and the objectives help to provide context when examining the magnitude of recorded exceedances.

During WYs 2011-2012, fecal coliform samples were only collected at the six Olema Creek sites in PORE; this sampling is organized by the San Francisco Bay RWQCB and is mandated by the Tomales Bay Pathogen TMDL Program. Fecal coliform samples were required to be processed by RWQCB's contracted laboratory (CEL Analytical), to ensure consistency and data comparability between all samples reported to the TMDL program, regardless of the partner organization collecting the samples. Total coliform and *E. coli* (TC/EC) samples were collected during every SFAN site visit of WYs 2011-2012 (at both primary and secondary sites). TC/EC samples were processed at the in-house laboratory at PORE. In this laboratory, TC/EC results are produced together from a single test. All bacteria samples were collected in sterile, factory-sealed bottles and stored immediately on ice.

Unlike the nutrient data that are often censored at the lower end (from non-detect results), the TC/EC data can be censored on either end due to the laboratory method used; this makes data analysis more challenging, and requires use of the Kaplan-Meier statistical method (through the NPSTORET database) to create summary statistics and figures (see Data Handling and Analysis section under Methods). In addition to the complication of censoring on both ends, the TC/EC data also have varying lower and upper quantification limits that differ between sites and seasons. Samples processed at the standard 10x dilution factor have a quantification range of 10 – 24,190 MPN/100 mL. During WYs 2011-2012, samples were also processed at 1x and 100x dilution factors, which resulted in quantification ranges of 1 – 2,419 MPN/100mL and 100 – 241,900 MPN/100 mL, respectively.

Summary statistics of all bacteria data collected during WYs 2011-2012 are displayed in detail in Tables 21, 22, 23, and 24; however, box and whiskers plots of these data are displayed separately (sorted by parameter) for simplified viewing. All mean values are arithmetic means. Sites with fewer than four results (STR3 and STR4) are included in the summary tables, but are excluded from the figures since their datasets are too small for analysis (U.S. EPA 1998). All summary statistics are based on instantaneous measurements routinely collected at approximately the same time of day on each visit; therefore, the data in the tables and figures presented do not reflect the true minimum and maximum values of diel variation.

Table 21. Pathogenic indicator bacteria results from Point Reyes National Seashore (water years 2011-2012). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	OLM18	OLM1	OLM14	OLM6A	OLM11	OLM10B	PNG3	PNG2	PNG1
Total coliform (MPN/ 100 mL)	Mean	14892.0	14149.0	14102.0	3428.0	23850.0	43739.0	1641.0	2196.0	4053.0
	Median	1200	1200	1100	1300	4900	4900	1200	1600	2600
	Minimum	440	280	500	500	570	880	210	420	880
	Maximum	>241900	>241900	242000	58000	>241900	>241900	9200	14000	>24190
	Std. dev.	53591.0	53699.0	53786.0	9182.0	64037.0	87321.0	1737.0	2722.0	4739.0
	# censored/ # results[1]	2/39	2/39	1/39	0/39	3/39	6/38	0/24	0/24	1/24
***E. coli* (MPN/ 100 mL)**	Mean	258.2	809.2	506.7	108.9	623.2	627.1	39.0	86.4	102.8
	Median	31	41	73	20	110	110	31	41	52
	Minimum	<10	<10	10	<10	20	<10	<10	<10	10
	Maximum	6800	26000	14000	2100	15000	13000	120	420	450
	Std. dev.	1081.0	4151.0	2232.0	339.4	2396.0	2125.0	33.7	95.5	115.3
	# censored/ # results[2]	4/39	2/39	0/39	3/39	0/39	1/38	5/24	4/24	0/24
Fecal coliform (MPN/ 100 mL)	Mean	81.4	147.4	111.6	55.2	206.5	170.1	-	-	-
	Median	50	50	80	30	170	80	-	-	-
	Minimum	<2	2	14	8	30	4	-	-	-
	Maximum	500	1600	500	300	900	900	-	-	-
	Std. dev.	112.3	299.3	104.1	67.8	183.8	186.6	-	-	-
	# censored/ # results[2]	3/31	0/31	0/32	0/32	0/31	0/32	-	-	-

[1] These censored results are '> QL' (above the quantification limit) & are shown as a ratio over the total number of results.
[2] These censored results are '< QL' (below the quantification limit) & are shown as a ratio over the total number of results.

Table 22. Pathogenic indicator bacteria results from Pinnacles National Park (water years 2011-2012). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	BG2	CHA3	CHA2	CHA1	MC1	SC3	SC2	SC1
Total coliform (MPN/ 100 mL)	Mean	2534.0	6084.0	2740.0	1117.0	77354.0	3348.0	1881.0	6682.0
	Median	1700	4100	1600	630	13000	2300	1200	5500
	Minimum	380	260	170	31	990	420	170	640
	Maximum	7300	>24190	16000	8200	>241900	20000	5500	24000
	Std. dev.	2059.0	6792.0	3417.0	1756.0	108875.0	4031.0	1592.0	6600.0
	# censored/ # results[1]	0/24	1/13	0/24	0/24	7/24	0/24	0/19	0/18
***E. coli* (MPN/ 100 mL)**	Mean	73.1	15.5	124.3	70.4	22636.0	223.6	74.6	384.1
	Median	20	-	31	20	560	160	20	150
	Minimum	<10	<10	<10	<10	31	<10	<10	10
	Maximum	910	62	1800	410	>241900	860	620	1500
	Std. dev.	184.8	14.5	361.7	102.6	67876.0	234.3	141.3	474.0
	# censored/ # results[2]	7/24	9/13	5/24	8/24	2/24*	1/24	3/19	0/18

[1] These censored results are '> QL' (above the quantification limit) & are shown as a ratio over the total number of results.
[2] These censored results are '< QL' (below the quantification limit) & are shown as a ratio over the total number of results.
* MC1 is the only exception – this site produced two censored results above the quantification limit.

Table 23. Pathogenic indicator bacteria results from Golden Gate National Recreation Area (water years 2011-2012). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	RC1	GERB1	OAK1	NYH1	TV1	TV2	TV3
Total coliform (MPN/ 100 mL)	Mean	1500.0	1802.0	2668.0	6393.0	2480.0	5291.0	3947.0
	Median	1400	1600	1200	3400	1200	3100	2700
	Minimum	350	590	320	680	540	360	350
	Maximum	4900	4400	>24190	>24190	10000	>24190	24000
	Std. dev.	1178.0	960.3	5114.0	7788.0	2958.0	6781.0	4689.0
	# censored/ # results[1]	0/24	0/24	1/22	3/24	0/12	2/20	0/24
E. coli **(MPN/ 100 mL)**	Mean	42.3	118.2	1002.0	1303.0	207.3	37.9	54.0
	Median	20	41	85	110	-	20	30
	Minimum	<10	<10	<10	10	<10	<10	<10
	Maximum	290	1200	17000	>24190	1500	210	460
	Std. dev.	57.3	245.2	3598.0	4922.0	439.7	47.9	91.3
	# censored/ # results[2]	3/24	2/24	3/22	1/24*	1/12	6/20	5/24

[1] These censored results are '> QL' (above the quantification limit) & are shown as a ratio over the total number of results.
[2] These censored results are '< QL' (below the quantification limit) & are shown as a ratio over the total number of results.
* NYH1 is the only exception – this site produced one censored results above the quantification limit.

Table 24. Pathogenic indicator bacteria results from John Muir National Historic Site (water years 2011-2012). All means and standard deviations are rounded to one more decimal place than the least precise value (least number of decimal places) of each corresponding dataset.

Parameter	Statistic	FRA1	STR3	STR4
Total coliform (MPN/ 100 mL)	Mean	10620.0		
	Median	9200		
	Minimum	760	20000	>24190
	Maximum	>24190	>24190	>24190
	Std. dev.	8588.0		
	# censored/ # results[1]	5/21	1/2	2/2
E. coli **(MPN/ 100 mL)**	Mean	2222.0		
	Median	440		
	Minimum	10	72	530
	Maximum	17000	750	2100
	Std. dev.	4570.0		
	# censored/ # results	0/21	0/2	0/2

[1] These censored results are '> QL' (above the quantification limit) & are shown as a ratio over the total number of results.

Total Coliform

The contact recreation maximum for total coliform, established by the San Francisco Bay RWQCB's Basin Plan, is 10,000 MPN/100mL for a single sample. During WYs 2011-2012, a total of 650 total coliform samples were collected from the SFAN water quality sites; 12% of all results (77 of 650) exceeded the contact recreation maximum, and exceedances were found in every park unit.

A total of 305 bacteria samples were collected from the PORE sites during WYs 2011-2012, and 11% of these (34 of 305) exceeded the objective maximum of 10,000 MPN/100mL; the majority of these exceedances (32 of 34) were from the Olema Creek sites, and one third of them were collected during storm events (Figure 33). The PINN sites had a similar rate of exceedance (14%); however, only one exceedance (of 23) was captured during a storm event. The six lowest PINN results came from site CHA1 in Chalone Creek, which also produced the lowest mean total coliform value in the SFAN (1,117 MPN/100mL) (Figure 34). MC1 in McCabe Canyon produced the highest mean total coliform value in the SFAN (77,354 MPN/100mL), as well as the seven highest results in PINN. Each of these seven individual results exceeded the method's quantification limit; six exceeded the upper limit of 24,190 MPN/100mL (processed at a 10x dilution), and one result exceeded the upper limit of 241,900 MPN/100mL (processed at a 100x dilution).

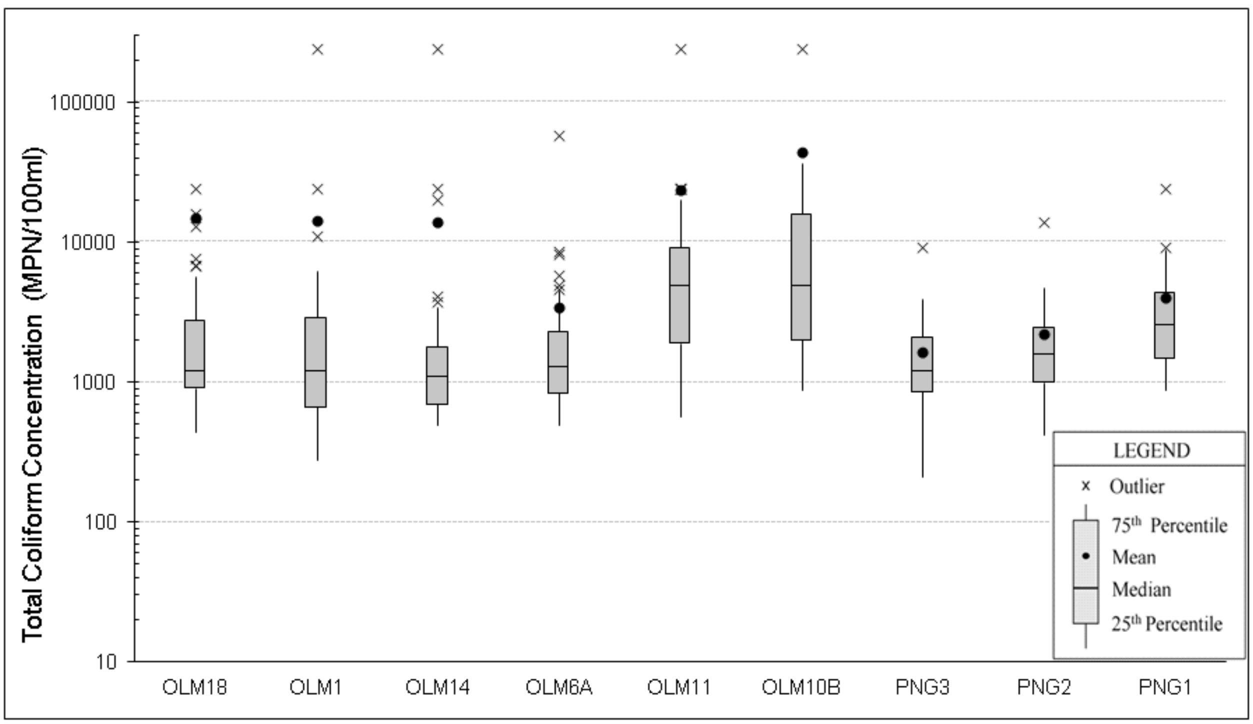

Figure 33. Total coliform results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

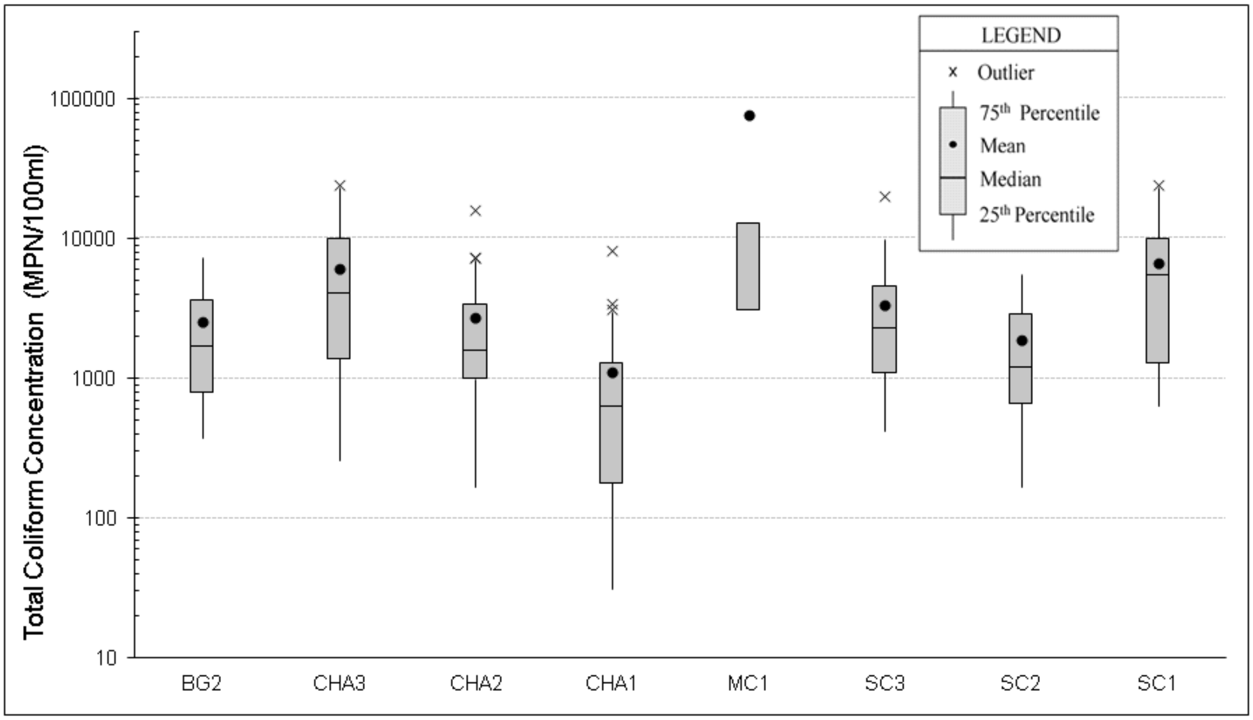

Figure 34. Total coliform results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for site MC1 (high censoring prevented computation).

The GOGA total coliform results exhibited the lowest rate of exceedance (5%), while the JOMU results exhibited the highest (48%). Approximately half of these exceedances were from samples collected during storm events. Of the GOGA results that exceeded the 10,000 MPN/100mL objective maximum, half of these were from site NYH1 in Nyhan Creek; this site also produced the highest mean total coliform value in GOGA (6,393 MPN/100mL). The GOGA site with the lowest mean total coliform value (1,500 MPN/100mL) was RC1 in Rodeo Creek (Figure 35). FRA1 in JOMU produced a much higher total coliform mean than any of the GOGA sites (10,620 MPN/100mL), but it was still lower than many of the PORE and PINN mean values (Figure 36).

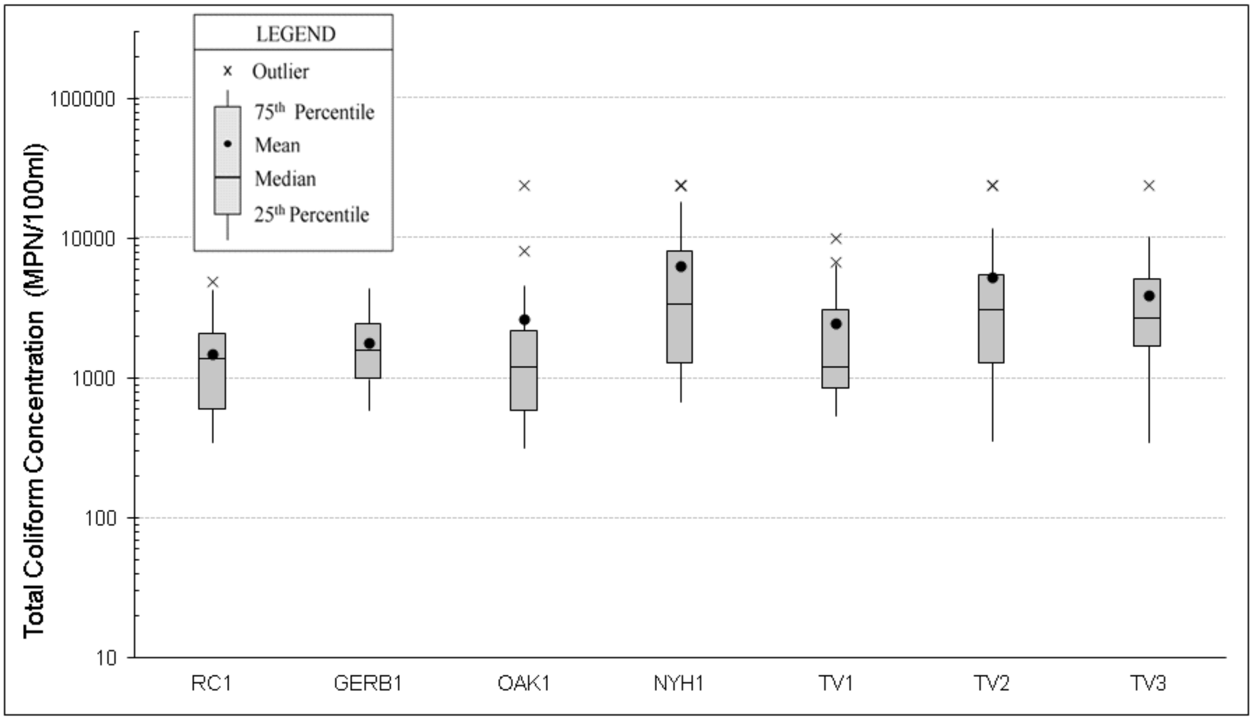

Figure 35. Total coliform results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range.

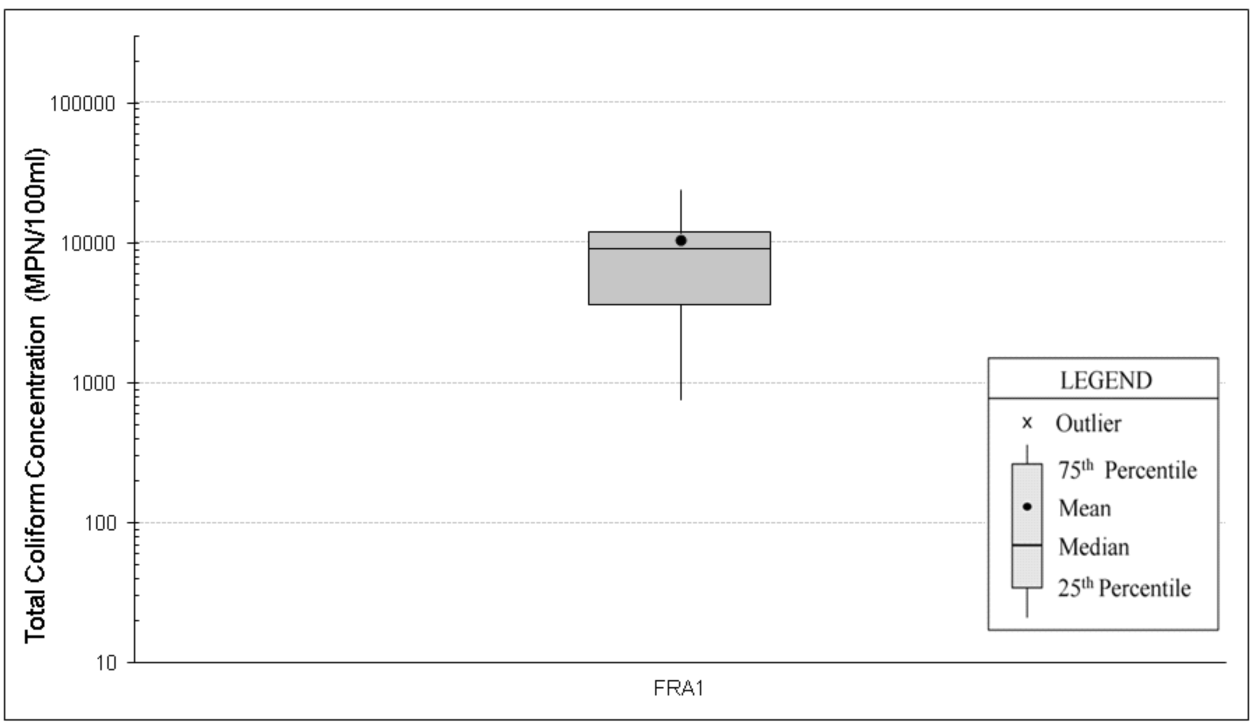

Figure 36. Total coliform results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

Escherichia coli (E. coli)

The contact recreation maximum for *E. coli*, established by the San Francisco Bay RWQCB's Basin Plan, is 235 MPN/100mL for a single sample. During WYs 2011-2012, a total of 650 *E. coli* samples were collected from the SFAN water quality sites; 18% of these results (120 of 650) exceeded the contact recreation maximum, and exceedances were found in every park unit. Eleven percent of all samples (72 of 650), program-wide, were reported as non-detect (below the quantification limit of 1, 10, or 100 MPN/100mL, depending on the dilution used); several non-detects were found in the PORE, PINN, and GOGA datasets, while all JOMU results were above the detection limit.

A total of 305 bacteria samples were collected from the PORE sites during WYs 2011-2012, and 15% of these exceeded the objective maximum of 235 MPN/100mL. Of these exceedances, approximately one quarter were collected during storm events, and 89% (42 of 47) were from the Olema Creek sites. Six percent of all PORE *E. coli* results were reported as non-detect, and approximately half of these were from the Pine Gulch sites; these sites also produced the three lowest mean *E. coli* values in PORE (Figure 37). The highest mean *E. coli* value in PORE (809 MPN/100mL) was from site OLM1 in John West Fork, a tributary in the upper Olema Creek watershed.

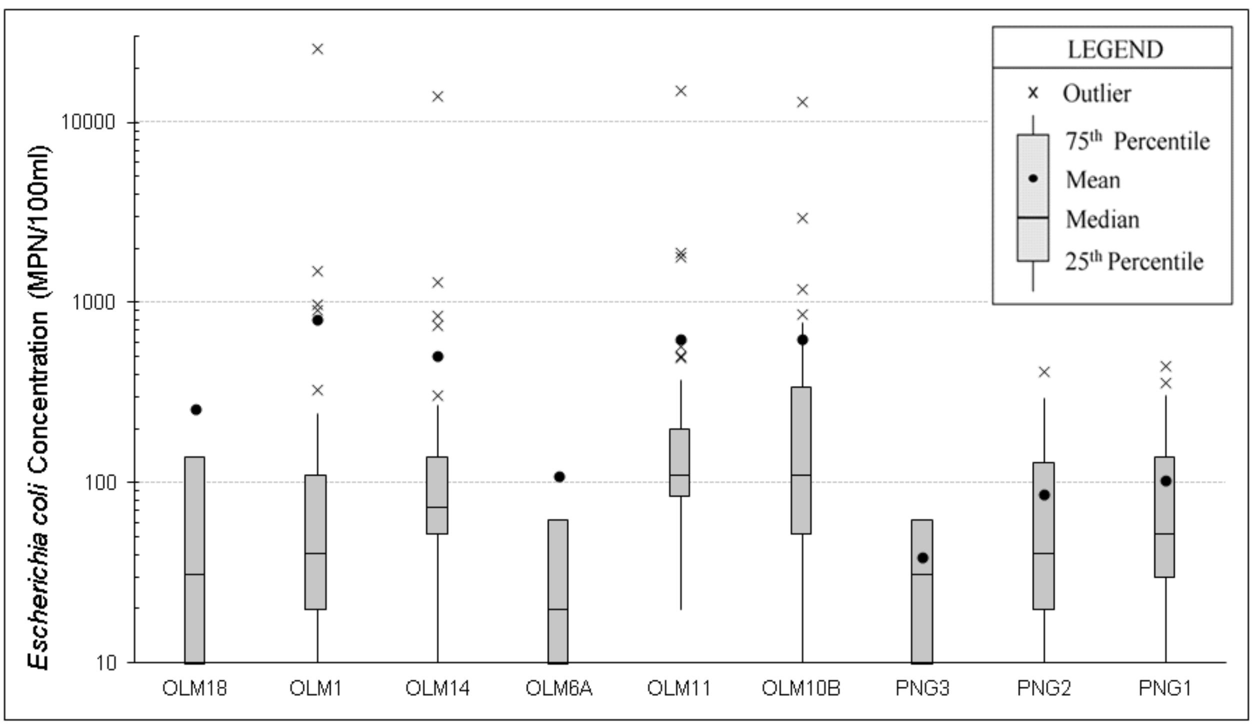

Figure 37. *Escherichia coli* results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for sites OLM18, OLM6A, and PNG3 (high censoring prevented computation).

The PINN *E. coli* results were highly varied; the lowest *E. coli* mean in the SFAN was found here, as well as the highest. During WYs 2011-2012, a total of 170 *E. coli* samples were collected from PINN. Nineteen percent of these results (33 of 170) were reported to be below the laboratory reporting detection limit, and the majority of these non-detects (22 of 33) were from Chalone Creek sites CHA1, CHA2, and CHA3. Site CHA3, on the North Fork of Chalone Creek, consistently produced low *E. coli* results during WYs 2011-2012; even during storm sampling in March 2011 its measured result was 20 MPN/100mL (one of the lowest quantified values). Due to the high percentage of non-detect results, this site could not be included in Figure 38. Site BG2 in Bear Gulch produced 11 of the lowest results in PINN (seven non-detect and four of 10 MPN/100mL). The six highest results found in PINN during WYs 2011-2012 were from site MC1 in McCabe Canyon; five of these were recorded during consecutive visits, from May 2012 through September 2012. The highest individual result recorded in the SFAN program during WYs 2011-2012 was collected from MC1 during August 2012 (an exceedance of the highest quantification limit; above 241,900 MPN/100mL).

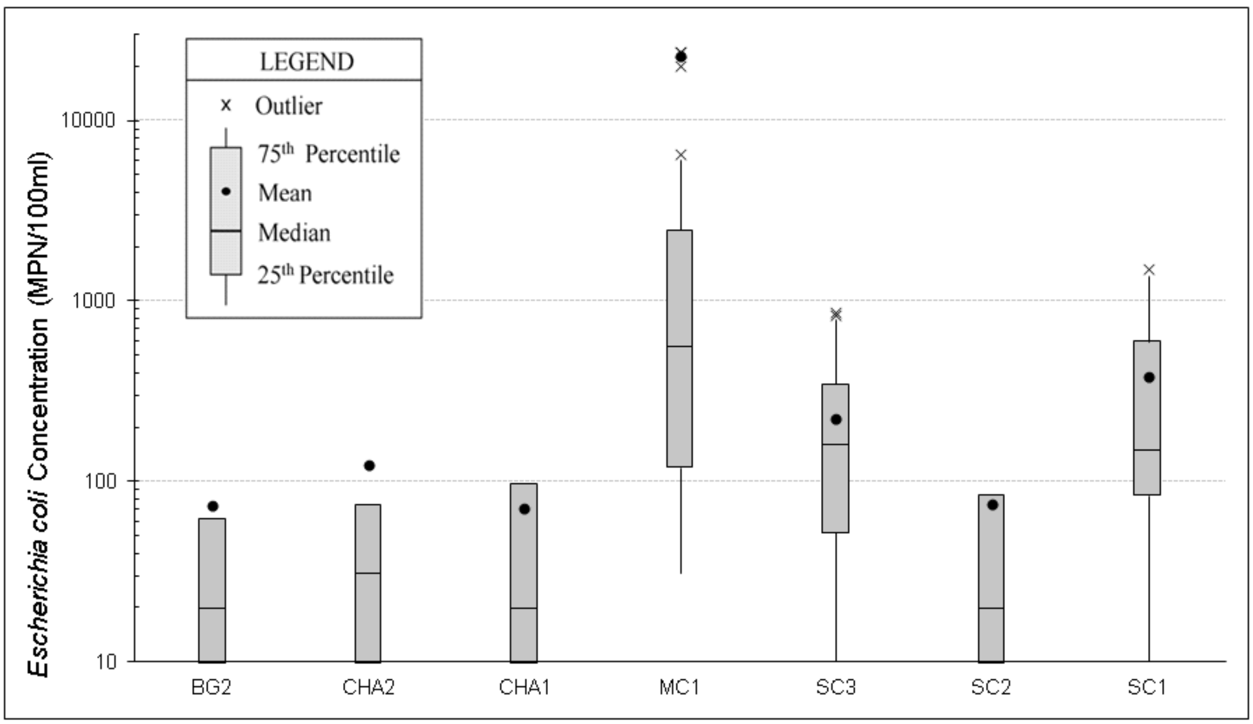

Figure 38. *Escherichia coli* results from Pinnacles National Park (water years 2011-2012). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for sites BG2, CHA2, CHA1, and SC2 (high censoring prevented computation). CHA3 was excluded due to its high percentage of censored data.

Similar to the total coliform dataset, the GOGA *E. coli* results exhibited the lowest rate of exceedance in the SFAN (13%), while the JOMU results exhibited the highest (76%). An additional 13% of the GOGA results (20 of 150) were reported as non-detect, while all JOMU samples contained quantifiable levels of *E. coli* (no non-detects). Of the GOGA results that exceeded the objective maximum (235 MPN/100mL), 15% were collected during storm events, while 32% of the JOMU exceedances corresponded with storm events. GOGA site NYH1, in Nyhan Creek, produced the highest total coliform mean, and it also produced the highest *E. coli* mean (1,303 MPN/100mL) compared to all other GOGA sites. The GOGA site with the lowest *E. coli* mean (37.9 MPN/100mL) was site TV2 in Tennessee Valley Creek (Figure 39). Site FRA1 in JOMU produced a few of the highest individual *E. coli* results, and its mean value of 2,222 MPN/100mL was the second highest in the SFAN (Figure 40).

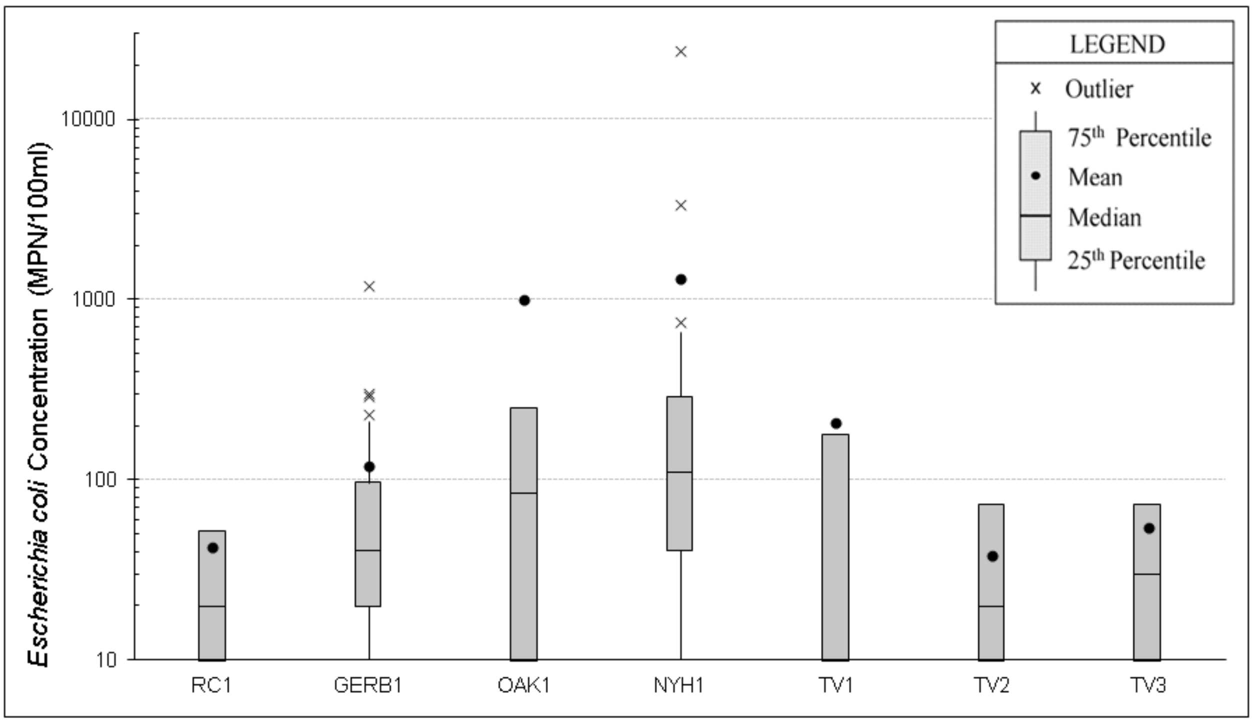

Figure 39. *Escherichia coli* results from Golden Gate National Recreation Area (water years 2011-2012). Boxplots present the interquartile range of each dataset. Whiskers are drawn to 1.5 times the interquartile range, except for sites RC1, OAK1, TV1, TV2, and TV3 (high censoring prevented computation).

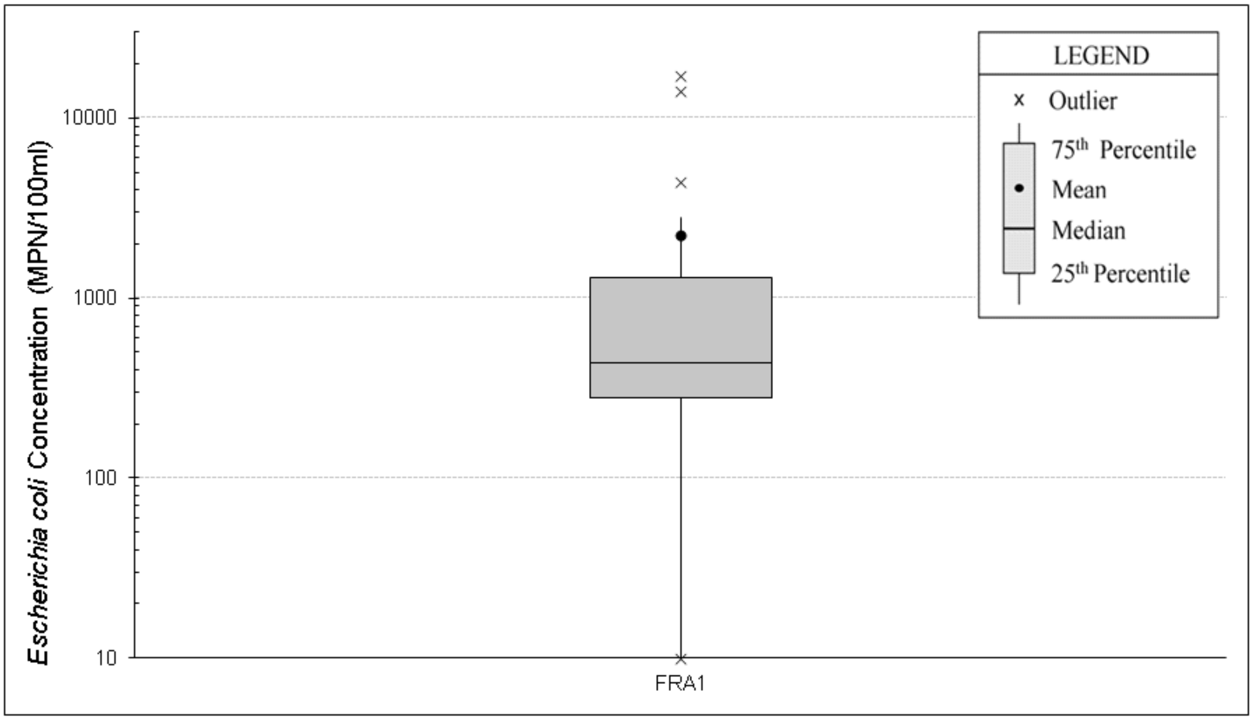

Figure 40. *Escherichia coli* results from John Muir National Historic Site (water years 2011-2012). The boxplot presents the interquartile range of the dataset; whiskers are drawn to 1.5 times the interquartile range.

Fecal Coliform

The contact recreation maximum for fecal coliform, established by the San Francisco Bay RWQCB's Basin Plan, is 400 MPN/100mL for a single sample. The sampling plan for the Tomales Bay Pathogen TMDL Program includes an intensive fecal coliform sampling period of five consecutive weeks, in the winter and summer, in addition to routine monthly monitoring. During this reporting period, the seasonal weekly sampling took place in March and July of WY 2011, then during January and July of WY 2012. As guided by the RWQCB, monthly fecal coliform monitoring did not take place during February or May of 2012, or during the first five months of WY 2011. None of the scheduled sampling days overlapped with storm sampling events.

During WYs 2011-2012, a total of 189 fecal coliform samples were collected from the Olema Creek sites. Six percent of these results (12 of 189) exceeded the contact recreation maximum of 400 MPN/100mL; exceedances were found at every site, except for site OLM6A, which also produced the lowest mean fecal coliform value (55.2 MPN/100mL) as well as the lowest *E. coli* mean value in the Olema Creek watershed (108.9 MPN/100mL). Two percent of all fecal coliform results (3 of 189) were reported as non-detect, and each of these was collected from the farthest upstream site (OLM18), which also produced a relatively low mean (81.4 MPN/100mL). The two highest means were calculated from the farthest downstream sites, OLM11 and OLM10B (Figure 41).

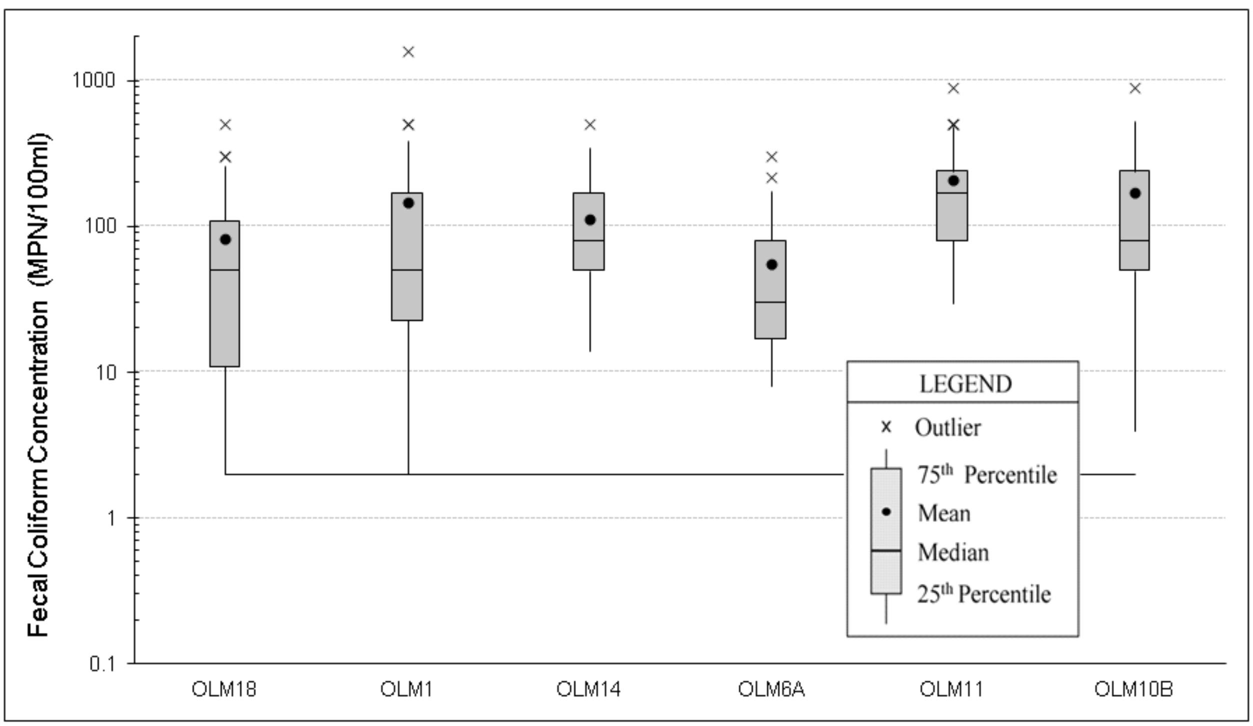

Figure 41. Fecal coliform results from Point Reyes National Seashore (water years 2011-2012). Boxplots present the interquartile range of each dataset; whiskers are drawn to 1.5 times the interquartile range. The laboratory reporting detection limit (2 MPN/100mL) is displayed with a solid line.

Conclusions

Thirty water quality sites were monitored within four SFAN park units during WYs 2011-2012, and the resulting data show that waters commonly met most established water quality objectives. Overall, the PORE results commonly met their respective objectives, while the JOMU results infrequently met the water quality objectives for most monitored parameters. The PINN and GOGA results exhibited highly varied exceedance rates depending on the parameter (Table 25).

Table 25. Percentages of results that failed to meet water quality objectives[1], sorted by NPS unit. The parameters of the greatest concern (15% failure rate or higher) are shaded for simplified viewing.

Parameter	PORE	PINN	GOGA	JOMU
Dissolved oxygen	7%	24%	18%	4%
pH	0%	9%	<1%	0%
Specific conductance	0%	40%	3%	92%
Turbidity	7%	21%	17%	31%
Nitrate (as nitrogen)	<1%	0%	0%	55%
Total coliform	11%	14%	5%	48%
Escherichia coli	15%	20%	13%	76%
Fecal coliform	6%	n/a	n/a	n/a

[1] Water quality objectives and corresponding references: > 7 mg/L dissolved oxygen (CA RWQCB 2010), 6.5 to 8.5 pH units applies to PORE/GOGA/JOMU (CA RWQCB 2010), 7.0 to 8.5 pH units applies to PINN (CA RWQCB 2011), < 500 µS/cm specific conductance (Behar 1997), < 25 NTU turbidity (Sigler et al. 1984), < 1.1 mg/L nitrate as nitrogen (Crunkilton 2000), < 10,000 MPN/100mL total coliform (CA RWQCB 2010), < 235 MPN/100mL *E. coli* (CA RWQCB 2010), and < 400 MPN/100mL fecal coliform (CA RWQCB 2010).

John Muir National Historic Site

The JOMU results exhibited the three highest exceedance rates for any monitored parameter: 92% of specific conductance results exceeded the ecological objective maximum of 500 µS/cm (Behar 1997), 76% of *E. coli* results exceeded the contact recreation objective maximum of 235 MPN/100mL, and 55% of nitrate (as N) results exceeded the ecological objective maximum of 1.1 mg/L. The nitrate results from JOMU stood out against all other SFAN sites; nearly all exceedances during WYs 2011-2012 (12 of 13) were from Franklin Creek samples, which also produced the highest mean value and the highest individual result in the SFAN. The total coliform and turbidity results from JOMU also exhibited high exceedance rates (48% and 31%, respectively). Conversely, dissolved oxygen and pH results were the only two parameters monitored in JOMU that commonly met the water quality objectives. pH results were consistently high at JOMU (relative to other SFAN sites), but all individual results met the established objective. Only one dissolved oxygen result fell below the established objective of 7 mg/L; this single value was recorded during low flow conditions when the creek was stagnant and barely flowing over the concrete ledge at the northern edge of the park boundary. Since this is the most urbanized watershed in the SFAN Freshwater Quality Monitoring Program, it is expected to produce different results than other SFAN watersheds.

Pinnacles National Park

The PINN water quality results revealed four parameters of concern, although only at specific sites. The highest exceedance rates for dissolved oxygen and pH were found in PINN (while these were the only two parameters *not* of concern at JOMU). The high rate of dissolved oxygen exceedance (24%) was attributed to half of the PINN sites only – the other half (CHA2, MC1, SC3, and SC1) exhibited consistently high results. The two lowest dissolved oxygen means in the entire SFAN program were found in PINN, at sites SC2 and CHA1. Site CHA1 also produced the highest mean water temperature value in the SFAN, which may explain its inability to hold dissolved oxygen.

Three other parameters in the PINN dataset exhibited high failure rates; 40% of specific conductance results exceeded the ecological objective maximum of 500 µS/cm (Behar 1997), 21% of turbidity results exceeded the ecological objective maximum of 25 NTU, and 20% of *E. coli* results exceeded the contact recreation objective maximum of 235 MPN/100mL. The majority of the specific conductance exceedances (80%) were from Sandy Creek sites, while the majority of the turbidity exceedances (71%) were from site MC1 in McCabe Canyon. Site MC1 also produced the six highest *E. coli* results in PINN, as well as the highest individual result and highest mean value in the SFAN program for both *E. coli* and TKN. SFAN staff alerted PINN park managers of the high *E. coli* levels at MC1 during WY 2012, and assisted park staff to plan additional monitoring activities to learn more about this stream system.

Golden Gate National Recreation Area

During WYs 2011-2012, the GOGA dataset revealed two parameters of concern - dissolved oxygen and turbidity – and site TV2 in Tennessee Valley Creek was determined to be of the highest concern. This site is alongside the Tennessee Valley Trail, and just downstream of the horse stables and equestrian center. For the majority of each water year, this site was often found to be fairly stagnant, with an oily sheen on the surface, and a channel full of orange pillowy clouds; these signs suggest the presence of iron bacteria (see Figure 31). Site TV2 produced the lowest dissolved oxygen reading on nearly every GOGA sampling day; the lowest dissolved oxygen result in the SFAN; the highest turbidity result and the highest mean turbidity value in the SFAN; the highest TKN result in the SFAN; and the second lowest *E. coli* mean in the SFAN. This site also produced most of the lowest pH values in GOGA and the second lowest pH mean in the SFAN. Additional monitoring of Tennessee Valley Creek, its nutrients, and its contributing sources may be worthwhile.

Point Reyes National Seashore

Water quality in the Pine Gulch and Olema Creek watersheds is of concern, as they support populations of coho and steelhead; fortunately, the results from these datasets during WYs 2011-2012 commonly fell within the water quality objectives. All PORE pH and specific conductance results (and nearly all nitrate results) fell within their respective objectives, and all other parameters demonstrated low rates of exceedance (less than 15%). This monitoring period revealed one parameter of concern: 15% of the PORE *E. coli* results exceeded the contact recreation maximum objective of 235 MPN/100mL. The majority of these (89%) were from the Olema Creek sites, while only five Pine Gulch results (of 47) exceeded the objective. High levels of pathogenic indicator bacteria in the Olema Creek watershed have been documented for many years, and monitoring of these levels continues through the San Francisco RWQCB's Tomales Bay Pathogen TMDL Program.

Summary

Two monitoring objectives proposed in the SFAN Freshwater Quality Monitoring Protocol are not addressed in this report: diel variability has not been evaluated because of significant needs for additional funding, staff time, and continuous monitoring equipment; loading has never been calculated by the San Francisco Bay RWQCB's Pathogen TMDL Program (nor is it a requirement of their program). This water quality monitoring program satisfies the third objective of the SFAN protocol, by determining the extent that the sites meet established federal and state water quality standards, through routine sampling.

The data presented in this report summarize the fifth and sixth years of monitoring under the SFAN Freshwater Quality Monitoring Protocol (Cooprider and Carson 2006). This two-year rotation (WYs 2011-2012) involved routine monitoring of 30 sites in four NPS units (PORE, PINN, GOGA, and JOMU), and it will be repeated in WYs 2015-2016. WYs 2013-2014 will repeat the sampling routine of the alternate rotation, which includes 25 different sites in three SFAN parks (GOGA, MUWO, and PORE) (Table 9). After WYs 2013-2014 there will be eight years of protocol implementation, but due to the rotating basin design, this will yield just four years of data for each of these SFAN watersheds. After WY 2014, more extensive data analysis will be considered, but it is likely that the first protocol objective (long-term trends analysis) will not be possible until there is a more substantial dataset.

During water years 2011 and 2012, this water quality program produced a clear snapshot of watershed health in eight SFAN watersheds. Continuation of this long-term monitoring program is necessary to document seasonal ecological fluctuations, determine trends, inform management decisions, and assist with evaluation of restoration projects.

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